

The work was purposed to identify the compositions the blended fuel of butanol, gasoline, and water forming the stable emulsions at low temperatures. The previous researches reported that the blending of butanol and gasoline generally employed the synthetic surfactants which were expensive and mixed at room temperatures. It is important to analyze the stability of the substances in the wide range of temperature for it alter significantly on the surface of the planet. The references survey revealed that the works of the compositions of the wet butanol and gasoline at low temperatures are yet published. The present work was successful to blend the butanol, gasoline, and water in stable emulsion without using the surfactant and stabilized in the less of room temperature. Compositions of butanol, gasoline (RONs 90), and water emulsified and stabilized at low temperatures without synthetic surfactants were successfully studied. It was found that aqueous butanol and gasoline formed a stable emulsion at low temperatures and discovered the phase was separated if temperature declined. The compositions of pure butanol, gasoline, and water recorded in stable emulsions using butanol 85.00 % ranged from 75.08–79.24 %, 6.77–11.67 %, and 13.25–13.98 %, respectively, blended at temperatures 0.00–29.70 °C. The usage of butanol 99.50 % caused the change of compositions recorded at 0.71–11.34 %, 88.61–99.29 %, and 0.00–0.06 % blended at 0.00–29.00 °C. It was discovered that the increase of butanol percentage of the fuel after the emulsion was stable tended to the emulsion kept one phase. The emulsion fuels found would be applied to the heat-modified engines operating in wide range temperatures which were below room temperature

Keywords: blended fuels, butanol-gasoline-water, stable emulsion at low temperatures, phase separation, non-surfactant

IDENTIFYING OF THE COMPOSITIONS OF THE BLENDED FUELS OF THE BUTANOL, GASOLINE, AND WATER STABILIZED AT LOW TEMPERATURES

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1. Introduction

The world is turning its energy from fossil- to renewable-based energy, and it is the most challenging work because of the considerable cost. Currently, scientists are finding the best solution to overcome the lack of fossil-based fuels, such as petroleum, gas, and coal. The efforts conducted

aim to avoid the decline of economic growth globally [1]. Renewable energies derived from plants, such as ethanol and biogas, have been used for years to obtain the standard fuels that can be applied to the engine [2, 3]. Ethanol has been developed and commercialized successfully in two countries, Brazil and the United States of America, for tens of years [4, 5].

Since the ethanol processed from either starchy or sugar material is still expensive, it is mixed with gasoline, forming a substance called gasohol (gasoline-ethanol) [6, 7]. The mixed fuels whose ethanol composition was 85 % and less than 10 %, assigned E85 and E10, can be employed in the modified- and conventional engines. Applying gasohol E10 to an unmodified engine was possible, for its properties were the most comparable to pure gasoline [8, 9]. The most challenging of ethanol commercialization as a fuel was the price, which is still more expensive than pure gasoline in many countries. Finding another renewable energy source processed from plants is necessary, and its properties are near gasoline and diesel.

The butanol synthesized by scientists from plants had properties close to gasoline and had been tested on the SI engine, resulting in good performance [10]. The n-butanol was also mixed successfully into diesel and gasoline and tested on a light diesel engine [11]. A detailed study of the utilization of butanol blended with gasoline concerning power, performance, fuel consumption, and emission characteristics of SI engines was done previously. Results showed that the engine power increased by 50 % when butanol was mixed with gasoline, and the emission of toxic gases declined significantly [12].

A comparative study of combustion and emission from butanol and gasoline fuels was measured and analyzed employing types of injection systems [13]. Another investigator reported that the combustion process of the butanol mixed with acetone and diesel of a diesel engine worked properly, characterized by increasing efficiency parameters and decreasing the dangerous gasses exhausted by the machine [14]. The composition of butanol blended into gasoline at 33 % was investigated deeply using an SI engine. The study obtained results that the gasoline blended with butanol at that percent decreased the CO₂ emission but was constant for the NO_x gas [15].

The references survey conducted as described previously are not yet explored and examined about the compositions study of the butanol, gasoline, and water stabilized at lower temperatures. Therefore, studies at identifying the compositions the blended fuel of butanol, gasoline, and water forming the stable emulsions at low temperatures are relevance.

2. Literature review and problem statement

The butanol, whose chemical formula was assigned as C₄H₉OH, conventionally could be derived from the carbohydrate (biomass) through hydrolysis and fermentation employing strain *Clostridia* (*C. beijerinckii* and *C. acetobutylicum*) [16]. The property of butanol, which is close to petroleum, is a density measured at 806 kg/m³ [17]. Reviewed by investigators, it was discovered that the boiling point and RONs of butanol were 117 °C and 96, respectively, whereby they were relatively close to gasoline [18]. Furthermore, the presence of this alcohol in the mixed fuel of the butanol-gasoline could increase the flashing and lengthen the combustion [19].

The mixture of butanol, ethanol, and gasoline was studied and tested in the Port-Fuel Injection (PFI) and two Gasoline Direct Injection (GDI) engines [20]. Results revealed that the composition of each fuel component influenced the emission of the PFI and GDI engines. Another work showed that the butanol composition introduced 30 % of fuel to the public vehicle, and then the effect on the environment was analyzed [21]. The study found that the utilization of buta-

nol-gasoline impacted the environment minimally compared to that of pure gasoline. Another other work reported the performance and combustion characteristics of ethanol and butanol were investigated and found that the combustion rate of butanol was less than that of the ethanol-butanol mixture since it has low RONs [22]. The blends of the butanol-ethanol showed a relative similarity with ethanol-gasoline, which indicated that butanol could be developed as the fuel.

As described previously, the reference study showed that adding butanol to gasoline or diesel increased the performance but declined the toxic emissions. The studies also revealed that butanol is an exciting substitute for gasoline or diesel. However, all literature reported that butanol-gasoline blends employed pure butanol and were stabilized at room temperatures and atmospheric pressure. Furthermore, in the reported works as described previously, no literature reported the detailed compositions of the butanol, gasoline, and water stabilized in the temperature range of 0 to 30 °C. It is crucial and urgent to investigate the stability of the emulsion of butanol and gasoline blended at low temperatures. Furthermore, it is necessary for there to be temperature fluctuations on the earth's surface. Another fact found in previous studies generally used chemical surfactants to accelerate stable emulsion formation. Employment, however, could be influencing the product's price, which would decrease its competitiveness.

The present work introduced the new emulsion fuel combination between aqueous butanol and gasoline without employing a surfactant. The mixing of the components was done at a lower temperature. Since the blending was conducted at a wide range of temperatures, the fuel could be introduced into the engine run in the regions with high-temperature alterations. It was assumed that the butanol purity was constant at any temperature, and volume contractions during mixing were ignored. Next, the two compositions, volume and percentage (%v/v) were presented. Since the temperature range on the planet's surface is variative, it is necessary to study the stability of the emulsions of butanol, gasoline, and water.

Therefore, the study on analyzing and developing aqueous butanol and gasoline in wide-range temperatures is an important work to be conducted. The research results could be a baseline for developing stable wet butanol gasoline fuels and applying them to the engine.

3. The aim and objective of the study

The study aims to identify the compositions of butanol, gasoline (RONs 90), and water in stable emulsion at low temperatures.

To achieve this aim, the following objectives are accomplished:

- to identify the composition of the pure butanol, gasoline, and water in a stable emulsion blended at low temperatures using butanol 85, 90, and 93.86 %;
- to examine the compositions of the pure butanol, gasoline, and water in a stable emulsion employing butanol 96.00 and 99.50 % stabilized at low temperatures.

4. Materials and methods of research

4. 1. Object and hypothesis of the study

The object of the study is the identification of the compositions of the butanol, gasoline, and water in the stable

emulsion which depended on the temperature. The main hypotheses stated that the compositions of butanol, gasoline, and water mixture change as a function of temperature and butanol purity as well as the optimal temperature of the substances tends to stabilize the emulsion. It assumed that the butanol and gasoline purities as the temperature was decreased, remained constant and there was no pressure change inside substances. Furthermore, the volume alteration of the butanol, gasoline, and water as temperature changed was ignored and the component vaporization was negligible. The blending process involved the complicated interaction between wet butanol and gasoline in which it was simplified. The work was just to calculate the composition of each component without analyzing the forces acting on the molecular scale.

4. 2. Chemicals

The attaining the objectives defined, the chemicals and apparatuses needed were prepared as follow: The 1-butanol (Merck & Co., NJ, USA) analysis grade, whose concentration was 99.50 %, was purchased commercially. The gasoline (RONs 90) employed in the blending process was obtained from Indonesia's state oil and gas company (PERTAMINA). The water was used to prepare aqueous butanol employed demineralized water (Yuasa, Japan; Resistivity $100 \times 10^4 \Omega \text{ cm}$; PH 7.00), and the wet butanol was obtained from pure one by dilution technique. The aqueous butanol whose concentrations were of 85, 90, and 96% was obtained using that technique. Tools employed were flasks (capacity 500, 100, and 25 ml), drops pipette, digital thermometer (TM902C), and freezer (TCF-210YID, TCL, China).

4. 3. Procedures

The research was aimed to prepare and to study the stable emulsions of butanol, gasoline and water at low temperatures. In this study was chosen the volume/volume ratio (%v/v) to determine component composition in blending process. The compositions were presented in tables and then equipped by triangular graphs. Both methods were employed in previous researches as reported [23, 24]. Procedures were as follows: The freezer tool, flasks, and thermometers were prepared, and butanol, whose concentrations of 85–99.50 %, was made by mixing pure and distilled water. First, the gasoline was poured into a 100 ml flask with a volume of 7.00 ml, and then butanol 85 % was mixed with gasoline gradually while being stirred gently. The mixture was observed until the butanol was dissolved uniformly with gasoline, forming a stable emulsion at room temperature (29.70 °C) assigned T_0 .

The sample was kept inside a flask and put inside the freezer at a lower temperature T_1 . The phase was separated into two components, aqueous butanol, and gasoline, set below, which volumes are assumed to be similar to the previous condition. Some butanol was added gradually while shaken until the emulsion was stabilized. After volumes were noted, the flask containing the second sample was put again inside the freezer, and the temperature decreased to T_2 , which was less than the previous temperature. The phase was also separated, and the emulsion was stabilized following the similar process mentioned above.

A similar method was conducted for butanol, which purities were 90.00, 93.86, 96.00, and 99.50 %, and the work proceeded to measure the fuel specifications carried out in different labs. The volume of pure butanol was ob-

tained by multiplication between the percentage- and total volume of butanol and the water. The composition was the ratio of the volume of components divided by volumes of butanol and gasoline. The table and triangular graphs presented the compositions based on the butanol concentration.

5. Results of a study of compositions of butanol, gasoline (RONs 90)-water in stable emulsions at low-temperature

5. 1. The composition of the pure butanol, gasoline, and water in a stable emulsion blended at low temperatures using butanol 85, 90, and 93.86 %

The preparation of the blended fuel, combining wet butanol and gasoline, was initiated by providing butanol whose concentrations were 85.00, 90.00, 93.86, and 96.00 % using the diluting technique, while 99.50 % was obtained commercially. Firstly, chemicals and tools were used in the room where temperatures and pressure were normal. The seven million liters of gasoline were poured gradually into a 100 ml flask. The wet butanol 85.00 % was added into the gasoline until the components were stabilized, and then each volume or composition was determined as shown in Table 1.

It was observed that the aqueous butanol 85.00 % was entirely mixed with 7.00 ml of gasoline at 53.00 ml, with compositions of the pure butanol, gasoline, and water were 75.08, 11.67, and 13.25 % blended at temperatures 29.70 °C. The sample was prepared, and chemicals (gasoline and butanol), including flasks, were removed to inside freezer equipment. The phases of the sample components started a separation that the thermometer displayed at 27.30 °C. The volume of the butanol, 85.00 %, was added by 2.50 ml to 55.50 ml gradually, and then the emulsion was stabilized. The sample and chemicals were put again in the freezer to decrease the temperature, which was less than the previous one. The component separation observed at the temperature showed 23.00 °C. Some butanol was added to 63.00 ml accumulated from the starting point until both substances were mixed uniformly.

Table 1

The composition of the pure butanol, gasoline, and water in a stable emulsion blended in the temperature range of 0.00–29.70 °C using butanol 85 %

T (°C)	Volume (ml)				Composition (%v/v)		
	Gasoline	Butanol 85.00 %	Pure butanol	Water	Pure butanol	Gasoline	Water
0.00	7.00	96.35	81.90	14.45	79.24	6.77	13.98
2.30	7.00	88.00	74.80	13.20	78.74	7.37	13.89
3.60	7.00	90.00	76.50	13.50	78.87	7.22	13.92
9.60	7.00	88.50	75.23	13.28	78.77	7.33	13.90
13.20	7.00	73.50	62.48	11.03	77.61	8.70	13.70
18.10	7.00	62.50	53.13	9.38	76.44	10.07	13.49
21.00	7.00	56.00	47.60	8.40	75.56	11.11	13.33
21.80	7.00	63.00	53.55	9.45	76.50	10.00	13.50
23.00	7.00	63.00	53.55	9.45	76.50	10.00	13.50
27.30	7.00	55.50	47.18	8.33	75.48	11.20	13.32
29.70	7.00	53.00	45.05	7.95	75.08	11.67	13.25

The blending proceeded for the lower temperatures; the procedures were similar to the previous steps described above. The emulsion became unstable when the sample was conditioned at temperatures less than 23.00 °C. The substance appeared clear after the volume of the butanol was increased to 90.00 ml at 3.60 °C, forming compositions of three components at 78.87 %, 7.22 %, and 13.92 %. Meanwhile, the butanol 85 % volume should be added as much as 96.35 ml to 7.00 ml of gasoline held at 0.00 °C, in which compositions were 79.24 %, 6.77 %, and 13.98 %. The data also showed an influence of the temperature decrease in which some added butanol volumes declined. Those are occurring at temperatures of 21.00, 9.60, and 88.0 °C. Generally, the amount of the butanol volume added was more significant than that of the compression of the volume.

To know the connection of the compositions of the pure butanol, gasoline, and water presented in 2D is drawn in the triangular graph. Fig. 1 is the triangular graph of the composition (in %v/v) of pure butanol, gasoline, and water in a stable emulsion in the temperature range of 0 to 29.70 C, employing butanol 85 %.

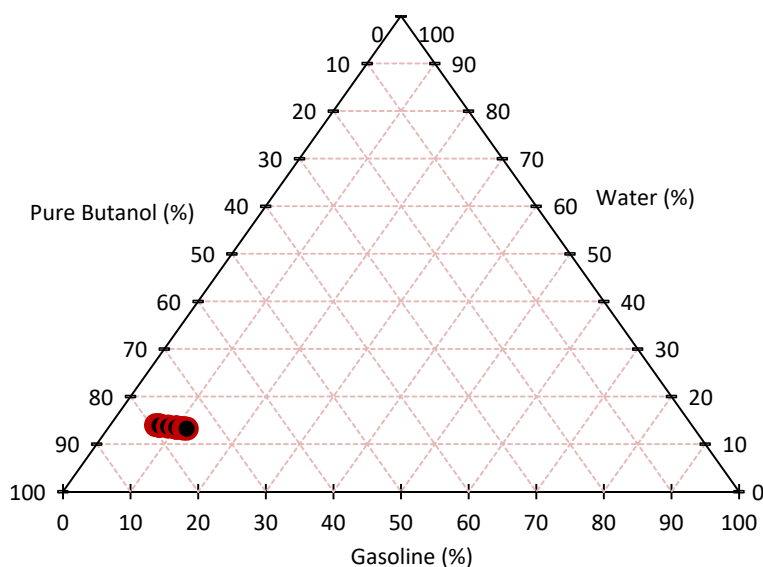


Fig. 1. The triangular perspective of the composition (in %v/v) of pure butanol, gasoline, and water in a stable emulsion in the temperature range of 0 to 29.70 °C employing butanol 85 %

The solid circles represent the compositions in which the substances are dissolved uniformly. The graph reveals that the increase of the butanol tends to the water composition is constant, as shown in the previous table. It was observed that the rise of the butanol did not change the stability of the emulsion but was not recorded oppositely. The incline of the temperature after the emulsion was stable kept being stabilized in its solution, but the decline tended to component separation. The trapezoidal area situated below the line could be the points of three components in stable emulsions.

The process was changed by increasing the butanol concentration from 85 % to 90 %, but the steps followed a similar method conducted previously. Table 2 presents the compositions of the pure butanol, gasoline, and water stabilized and blended in the temperature range of -0.50–27.30 °C using butanol 90 %. The mixing was initiated by combining the butanol and gasoline at room temperature,

recorded at 27.30 °C. Blending both substances needed 7 ml gasoline and 10.00 ml butanol. They were mixed uniformly. Pure butanol, gasoline, and water compositions were formed at 52.94 %, 41.18 %, and 5.88 %.

The decrease in temperature to 26.30 and 26.20 °C caused the component separation to move the gasoline to the upper side. Some amount of the butanol was added into the mixture, becoming 12.50 and 13.00 ml, respectively, until the components were emulsified clearly, which were proportional to compositions of 57.69, 35.90, and 6.41 % and 58.50, 35.00, and 6.50 %. However, the second observation for a similar temperature showed the volume of the substance decreased, indicating the volume contraction.

The sample was put again inside the freezer, and its temperature decreased to 24.80 and then 24.00 °C. Both temperatures caused the phase separation of aqueous butanol and gasoline to settle below- and above the sides. Adding wet butanol volume to 14.50 and 15.00 ml could stabilize the emulsion. The compositions of three components measured at the first and the second temperatures were 60.70, 32.56, 6.74 % and 61.36, 31.82, and 6.82 %.

A similar trend to the previous experiment is that the decrease in temperature tends to a phase separation and the addition of the butanol needed to overcome the stability of the emulsion. Blending the butanol and gasoline at low temperatures needed more butanol substance for both components to dissolve completely. The temperature decreased to 21.90, 21.60, 15.50, and 13.80 C needed 16.00, 14.50, 17.50, and 19.50 ml butanol volumes. Generally, the required butanol to be increased as the temperature declined unless the temperature was at 21.60 °C, whereby the volume contracted significantly.

The last three temperatures set at 2.80, 1.20, and -0.50 °C showed similar phenomena compared to previous data. The phase started separating into two components and was stabilized by adding the butanol volume to 20.00, 16.00, constricting, and 18.00 ml. Pure butanol, gasoline, and water compositions at the lowest temperature were recorded at 66.67 %, 25.93 %, and 7.41 %, the highest added butanol.

Fig. 2 is the triangular graph describing the composition of pure butanol, gasoline, and water, mixing uniformly in the temperature range of -0.50–27.30 °C, employing butanol 90 %. Compared to the previous graph utilizing butanol 85 %, the present graph shifted slightly to the right (before the reader). The shift means that the gasoline composition needed to be dissolved with butanol increased but decreased. The increase of the butanol after the emulsion was stabilized did not separate the phase. Meanwhile, the addition of gasoline tended to the forming of instability.

It was disclosed that there was an area inside the graph where the aqueous butanol and gasoline were in the stable emulsion. Based on the facts found in the experiments, there were points inside the graph where pure butanol, gasoline, and water components were permanently dissolved uniformly. The area was situated below the solid circles and trapezoidal shape that contained the unlimited numbers of composition combinations of the components. The solid circles, as

shown in the Fig. 2, are just the points at which the aqueous butanol and gasoline are just forming the stable emulsions.

The composition of the pure butanol, gasoline, and water in a stable emulsion blended in the temperature range of $-0.50-27.30\text{ }^{\circ}\text{C}$ using butanol 90 %

$T\text{ (}^{\circ}\text{C)}$	Volume (ml)				Composition (%v/v)		
	Gasoline	Butanol 90 %	Pure butanol	Water	Pure butanol	Gasoline	Water
-0.50	7.00	20.00	18.00	2.00	66.67	25.93	7.41
1.20	7.00	16.00	14.40	1.60	62.61	30.43	6.96
2.80	7.00	20.00	18.00	2.00	66.67	25.93	7.41
13.80	7.00	19.50	17.55	1.95	66.23	26.42	7.36
15.50	7.00	17.50	15.75	1.75	64.29	28.57	7.14
21.60	7.00	14.50	13.05	1.45	60.70	32.56	6.74
21.90	7.00	16.00	14.40	1.60	62.61	30.43	6.96
24.00	7.00	15.00	13.50	1.50	61.36	31.82	6.82
24.80	7.00	14.50	13.05	1.45	60.70	32.56	6.74
26.20	7.00	10.00	9.00	1.00	52.94	41.18	5.88
26.20	7.00	13.00	11.70	1.30	58.50	35.00	6.50
26.30	7.00	12.50	11.25	1.25	57.69	35.90	6.41
27.30	7.00	10.00	9.00	1.00	52.94	41.18	5.88

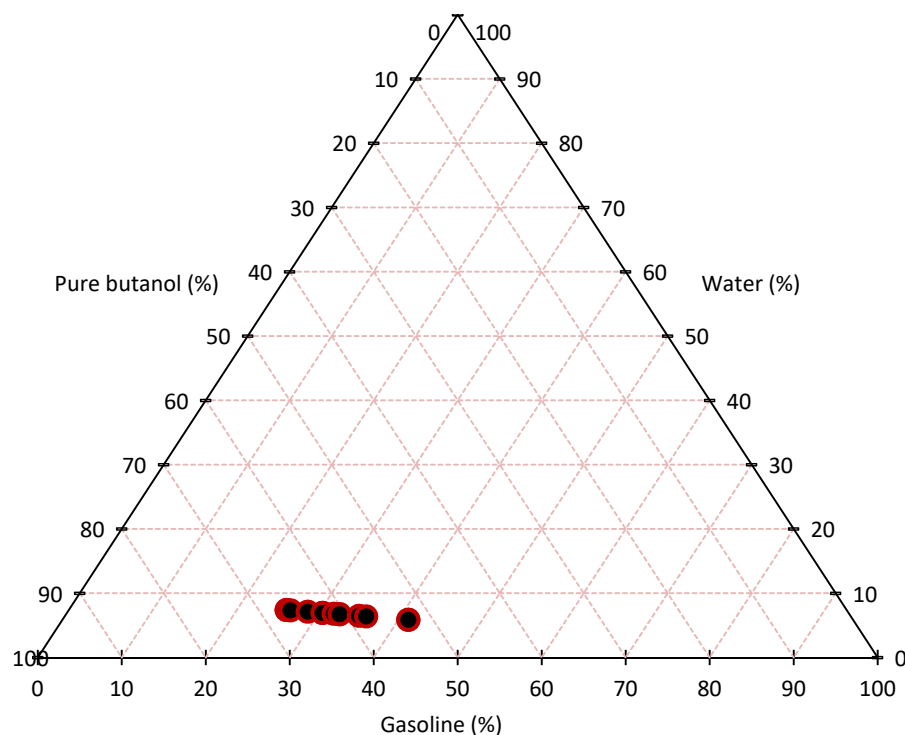


Fig. 2. The triangular perspective of the composition (in %v/v) of pure butanol, gasoline, and water in a stable emulsion in the temperature range of $-0.50-27.30\text{ }^{\circ}\text{C}$ employing butanol 90 %

The change of the butanol purity to 93.86 % significantly altered the combination of either the volume or the composition of the component in the stable emulsion

as presented in Table 3. The experiment of this butanol was successfully conducted from room temperature, $27.90\text{ }^{\circ}\text{C}$ until $-13.60\text{ }^{\circ}\text{C}$. The butanol added with gasoline increased as the blending temperature declined but was constant or decreasing, whereby the volume compression influenced those. The volume of petrol was stable at 7.00 ml, and the butanol volume added was a function of the blending temperature.

Table 2

The highest temperature needed the lowest butanol volume recorded at 3.00 ml, forming the compositions of the pure butanol, gasoline, and water were 28.15 %, 70.00 %, and 1.84 %. The lower temperatures needed, the higher the butanol to maintain the stability of the emulsion, which was relatively similar to the previous experiment. The butanol volume blended with gasoline at $25.00\text{ }^{\circ}\text{C}$ decreased to 2.00 ml, caused by the construction of the volume because of the temperature decrease. The trend proceeded to the lower temperatures in which the butanol blended was less than the initial amount.

The significant increase of the butanol volume blended started at a temperature of $13.80\text{ }^{\circ}\text{C}$ noted at 5.50 ml, and the compositions of the components dissolved were 41.30 % pure butanol, 56.00 % gasoline, and 2.70 % water, which were similarly held at $11.80\text{ }^{\circ}\text{C}$. The volume compression influenced the experiment employing butanol 93.86 % because of the cooling process. The data showed that the increase of butanol mixed was relatively small at every temperature when blending was conducted. A significant volume increase was observed at the last two temperatures, -5.70 and $-13.60\text{ }^{\circ}\text{C}$. The amounts of the butanol mixed at these temperatures were 7.00 and 9.00 ml, which were comparable to the compositions of the pure butanol gasoline and water at 46.93, 50.00, 3.07, and 52.80, 43.75, and 3.45 %.

The 2D representation could be where pure butanol, gasoline, and water are stable or unstable emulsions. Fig. 3 presents the triangular perspective of the composition of pure butanol, gasoline, and water entirely dissolved in the temperature range of $-13.60-27.90\text{ }^{\circ}\text{C}$ using butanol 93.86 %. The location of the solid circles complex shifted again to the right side (before the reader), which meant that the reduction of the butanol needed to be added into gasoline became a stable substance and was smaller compared to that of employing butanol at 90 %. The solid circles represent the equilibrium states between the aqueous butanol and gasoline at low temperatures.

Table 3

The composition of the pure butanol, gasoline, and water in a stable emulsion blended in the temperature range of -13.60 – 27.90 °C using butanol 93.86 %

T (°C)	Volume (ml)				Composition (%v/v)		
	Gasoline	Butanol 93.86 %	Pure butanol	Water	Pure butanol	Gasoline	Water
-13.60	7.00	9.00	8.45	0.55	52.80	43.75	3.45
-5.70	7.00	7.00	6.57	0.43	46.93	50.00	3.07
11.80	7.00	5.50	5.16	0.34	41.30	56.00	2.70
13.80	7.00	5.50	5.16	0.34	41.30	56.00	2.70
15.00	7.00	3.50	3.29	0.21	31.29	66.67	2.05
16.60	7.00	4.00	3.75	0.25	34.13	63.64	2.23
17.70	7.00	3.50	3.29	0.21	31.29	66.67	2.05
18.90	7.00	3.00	2.82	0.18	28.16	70.00	1.84
19.00	7.00	3.10	2.91	0.19	28.81	69.31	1.88
19.20	7.00	4.50	4.22	0.28	36.73	60.87	2.40
19.80	7.00	3.10	2.91	0.19	28.81	69.31	1.88
20.40	7.00	3.50	3.29	0.21	31.29	66.67	2.05
20.50	7.00	2.90	2.72	0.18	27.49	70.71	1.80
20.90	7.00	3.00	2.82	0.18	28.16	70.00	1.84
21.00	7.00	3.50	3.29	0.21	31.29	66.67	2.05
21.50	7.00	3.00	2.82	0.18	28.16	70.00	1.84
22.60	7.00	3.00	2.82	0.18	28.16	70.00	1.84
22.80	7.00	2.50	2.35	0.15	24.70	73.68	1.62
23.00	7.00	3.50	3.29	0.21	31.29	66.67	2.05
23.00	7.00	2.50	2.35	0.15	24.70	73.68	1.62
23.40	7.00	3.50	3.29	0.21	31.29	66.67	2.05
23.70	7.00	3.00	2.82	0.18	28.16	70.00	1.84
23.90	7.00	2.80	2.63	0.17	26.82	71.43	1.75
24.00	7.00	2.80	2.63	0.17	26.82	71.43	1.75
24.10	7.00	2.00	1.88	0.12	20.86	77.78	1.36
25.00	7.00	2.00	1.88	0.12	20.86	77.78	1.36
25.10	7.00	3.00	2.82	0.18	28.16	70.00	1.84
25.80	7.00	2.00	1.88	0.12	20.86	77.78	1.36
25.80	7.00	2.50	2.35	0.15	24.70	73.68	1.62
25.90	7.00	3.50	3.29	0.21	31.29	66.67	2.05
26.50	7.00	2.50	2.35	0.15	24.70	73.68	1.62
26.50	7.00	3.00	2.82	0.18	28.16	70.00	1.84
27.90	7.00	3.00	2.82	0.18	28.16	70.00	1.84

The water compositions get smaller if the purity of the butanol increases in a stable emulsion, and the points are very close to the line representing the gasoline compositions. The graph also reveals where three components, pure butanol, gasoline, and water, are mixed uniformly and clearly. The location is below the equilibrium line in which the combination numbers of the three components are unlimited. It was discovered that adding the butanol referred from a stable emulsion would not cause a phase separation similar to the increase in temperature. The lowest temperature held at -13.60 °C belonged to the point located at the leftmost (before the reader), and the highest one was at the rightmost of the solid circles. Adding the gasoline into the substance

after forming a stable emulsion would tend to a phase separation at every temperature. To stabilize the emulsion, the amount of butanol must be increased inside the substance.

The data showed in the previous experiments and used butanol 85.00, 90.00, and 93.86 % presented a similar trend regarding temperature composition change. Generally, the wet butanol mixed with gasoline increased as the temperature declined, but some data deviated, whereby the composition was constant or reduced because of the volume contraction. The increase of the butanol purity shifted the equilibrium lines to the right, which meant the gasoline composition inclined, or the butanol decreased, forming a stable solution.

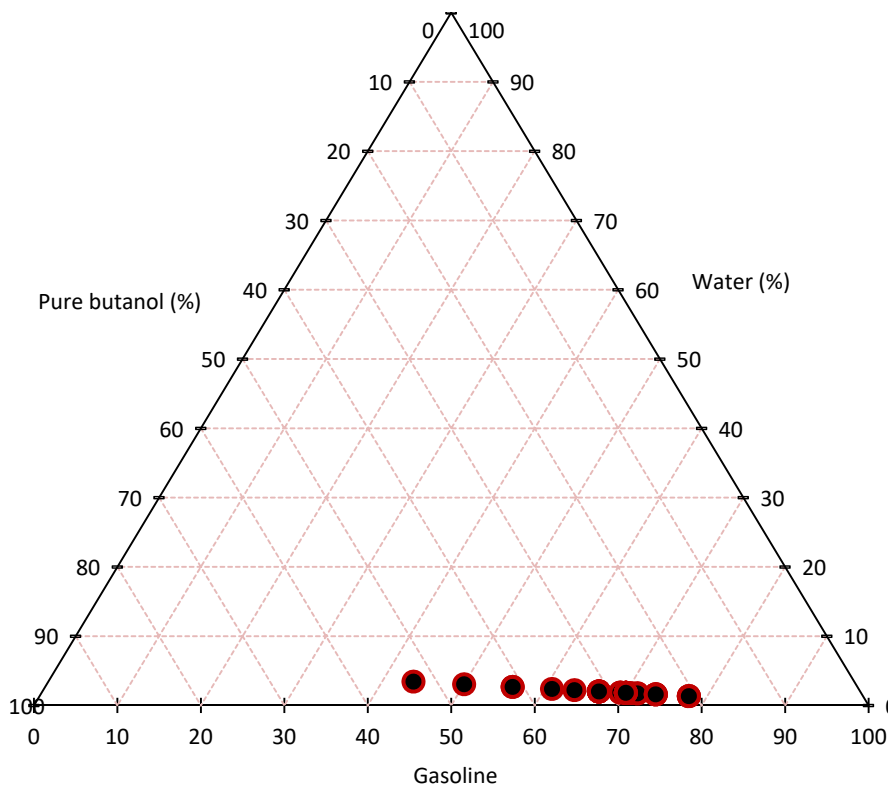


Fig. 3. The triangular perspective of the composition (in %v/v) of pure butanol, gasoline, and water in a stable emulsion in the temperature range of $-13.60-27.90\text{ }^{\circ}\text{C}$ employing butanol 93.86 %

5. 2. The compositions of the pure butanol, gasoline, and water in a stable emulsion employing butanol 96.00 and 99.50 % stabilized at low temperatures

Similar phenomena employed the higher butanol concentrations of 96.00 % and 99.50 %, as presented in Tables 4, 5, supported by Fig. 4, 5. Since the butanol concentrations increase, the equilibrium lines assigned by the solid circles are close to the gasoline composition line. It means that the higher butanol concentration, only a fraction of the butanol blended with gasoline, forms a stable emulsion. Observing and measuring the volume of the butanol poured into gasoline was challenging because its amount was small.

Table 4 presents the compositions of pure butanol, gasoline, and water dissolved in a stable emulsion and blended in the temperature range of $-8.40-27.30\text{ }^{\circ}\text{C}$, employing butanol 96.00 %. The amount of the butanol mixed with 7.00 ml of the gasoline was 1.00 ml conducted at room temperature $27.30\text{ }^{\circ}\text{C}$, in which the compositions of the pure butanol, gasoline, and water were recorded at 12.00, 87.50, and 0.50 %. The temperature decreased to 25.20 until $-8.40\text{ }^{\circ}\text{C}$ appeared to be a phase separation to aqueous butanol and gasoline. To stabilize the emulsion at the lowest temperature, 3.50 ml was added, but at $-2.50\text{ }^{\circ}\text{C}$ was mixed 2.00 ml butanol. The compositions of three substances were observed at 32.00 %, 66.67 %, and 1.33 % and at 21.33 %, 77.78 %, and 0.89 %, in which the butanol parts were the most prominent fuel in this experiment. The pure butanol, gasoline, and water composition range in stable

emulsion dissolved at $-8.40-27.30\text{ }^{\circ}\text{C}$ could be written as 12.00–32.00 %, 66.67–87.50 %, and 0.50–1.33 %.

Table 4

The compositions of the pure butanol, gasoline, and water in a stable emulsion blended in the temperature range of $-8.40-27.30\text{ }^{\circ}\text{C}$ employing butanol 96.00 %

T (°C)	Volume (ml)				Composition (%v/v)		
	Gasoline	Butanol 96.00 %	Pure butanol	Water	Butanol	Gasoline	Water
-8.40	7.00	3.50	3.36	0.14	32.00	66.67	1.33
-2.50	7.00	2.00	1.92	0.08	21.33	77.78	0.89
7.50	7.00	1.80	1.73	0.07	19.64	79.55	0.82
11.90	7.00	1.50	1.44	0.06	16.94	82.35	0.71
12.70	7.00	1.75	1.68	0.07	19.20	80.00	0.80
19.00	7.00	1.75	1.68	0.07	19.20	80.00	0.80
19.40	7.00	1.25	1.20	0.05	14.55	84.85	0.61
21.20	7.00	1.25	1.20	0.05	14.55	84.85	0.61
23.10	7.00	1.10	1.06	0.04	13.04	86.42	0.54
24.00	7.00	1.00	0.96	0.04	12.00	87.50	0.50
24.80	7.00	1.50	1.44	0.06	16.94	82.35	0.71
25.20	7.00	1.20	1.15	0.05	14.05	85.37	0.59
27.30	7.00	1.00	0.96	0.04	12.00	87.50	0.50

Since the amount of butanol blended with gasoline was small, the area where the substances were stable was tiny between the equilibrium and gasoline composition lines, as shown in the figure below. The perspective description of the triangular graph of the compositions (in %v/v) of pure butanol, gasoline, and water in a stable emulsion in the temperature range

of $-8.40-27.30\text{ }^{\circ}\text{C}$ introducing butanol 96.00 % was shown in Fig. 4. Though the area describing of the three substances were dissolved, the combinations of the compositions were infinite numbers. The area where the three components are separated is much higher than that of the stable condition. The Fig. 4 explains that wet butanol (96.00 %) can form a durable solution with gasoline in a wide range of temperatures, and the gasoline composition was dominating compared to that of butanol. It means that the blended fuel involving butanol 96.00 % could be employed in the heat engine combustion; furthermore, the water composition was just recorded at 0.50 %.

The last experiment conducted was blending the butanol 99.50 % with gasoline, in which the alcohol was a prime source

for the lower concentration. Similar to the previous work employing 96.00 %, it was difficult to determine the volume of butanol 99.50 % added to the gasoline. According to the data shown in Table 5, the butanol mixed is spread from 0.05 to 0.90 ml and 0.01 to 0.06 ml of water, as shown in Fig. 5. The measurement of the butanol volumes might have generated a significant error since the experiment used a 100 ml flask.

It was discovered that the differences in the butanol added to the two temperatures were slight, indicating that pure butanol (without water) could be blended with gasoline in a particular composition at every temperature. Based on the data trend shown from experiment 1 until 5, it was still a possibility.

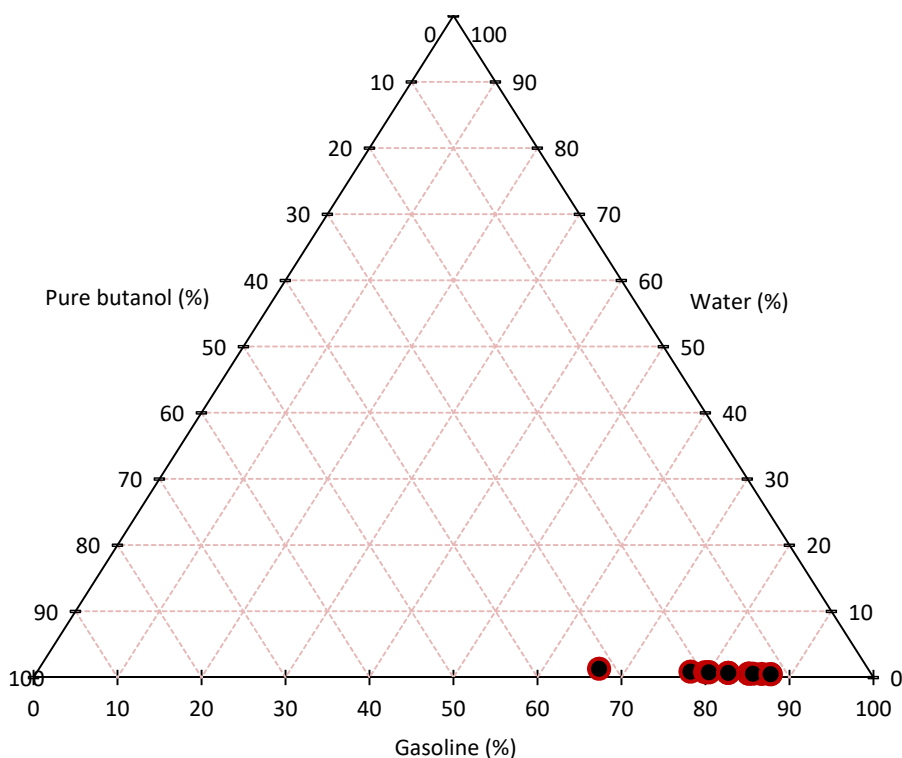


Fig. 4. The triangular perspective of the composition (in %v/v) of pure butanol, gasoline, and water in a stable emulsion in the temperature range of $-8.40-27.30\text{ }^{\circ}\text{C}$ employing butanol 96.00 %

Table 5

The composition of the pure butanol, gasoline, and water in a stable emulsion blended in the temperature range of $-0.00-29.00\text{ }^{\circ}\text{C}$ employing butanol 99.50 %

$T(^{\circ}\text{C})$	Volume (ml)				Composition (%v/v)		
	Gasoline	Butanol 99.50 %	Pure butanol	Water	Pure butanol	Gasoline	Water
0.00	7.00	0.90	0.90	0.00	11.34	88.61	0.06
13.70	7.00	0.50	0.50	0.00	6.63	93.33	0.03
14.70	7.00	0.50	0.50	0.00	6.63	93.33	0.03
20.40	7.00	0.40	0.40	0.00	5.38	94.59	0.03
20.60	7.00	0.40	0.40	0.00	5.38	94.59	0.03
23.80	7.00	0.40	0.40	0.00	5.38	94.59	0.03
25.70	7.00	0.30	0.30	0.00	4.09	95.89	0.02
25.80	7.00	0.20	0.20	0.00	2.76	97.22	0.01
26.10	7.00	0.20	0.20	0.00	2.76	97.22	0.01
26.50	7.00	0.20	0.20	0.00	2.76	97.22	0.01
26.90	7.00	0.20	0.20	0.00	2.76	97.22	0.01
29.00	7.00	0.05	0.05	0.00	0.71	99.29	0.00

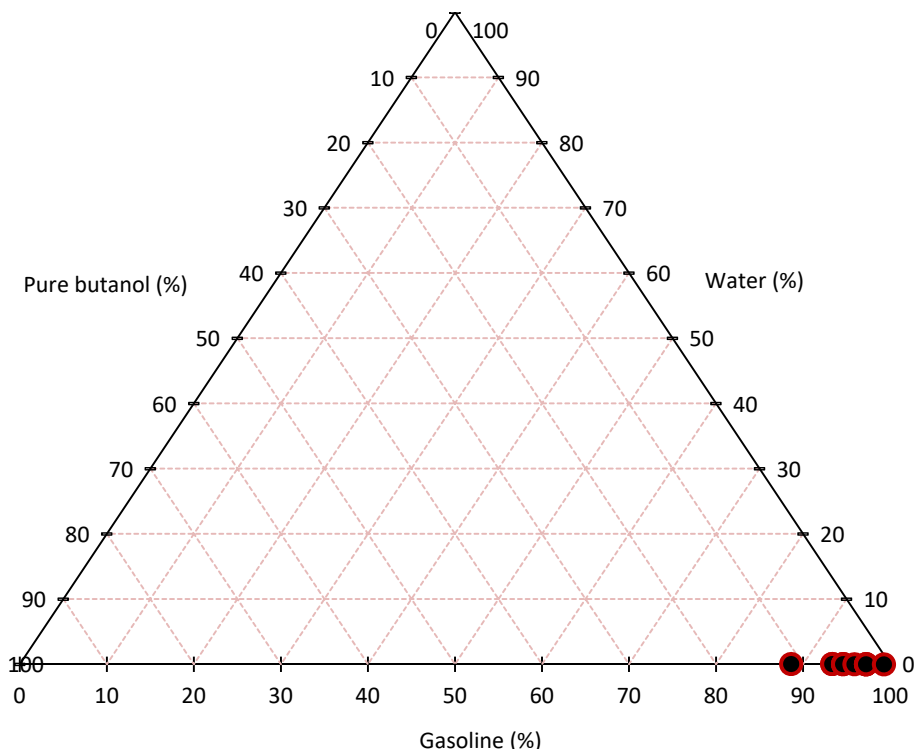


Fig. 5. The triangular perspective of the composition (in %v/v) of pure butanol, gasoline, and water in a stable emulsion in the temperature range of $-0.00-29.00$ °C employing butanol 99.50 %

The expectation was enhanced by the movement of the equilibrium line from left to the right side and almost overlapped with the gasoline composition line, as shown in Fig. 5, presenting the triangular perspective of the composition (in %v/v) of pure butanol, gasoline, and water in a stable emulsion in the temperature range of $-0.00-29.00$ °C employing butanol 99.50 %. The graph shows that the equilibrium line is situated on the gasoline line. The compositions of the pure butanol, gasoline, and water, as assigned in the table and figure, are written in the range values 0.71–13.4, 88.61–99.29, and 0.01–0.06 %.

6. Discussion of the compositions of the butanol-gasoline-water stabilized at low temperatures

The butanol 85.00 % was the lowest concentration, which could be blended with gasoline as long as we observed in the experiment. The butanol, whose purity was less than 85.00 %, got a white substance and separated, which was under investigation. Generally, the butanol 85.00–93.86 % blended with gasoline usage showed that the stable substance appeared clear as presented in Tables 1–3 and Fig. 1–5. However, in some circumstances, the stable emulsion separated into two phases if the dilution process was not conducted as a procedure and the sample was stored inside the freezer. A small part of the butanol was added to stabilize the emulsion at low temperatures until the substance became clear.

It was discovered that all samples prepared and blended in which they were mixed inside the freezer maintained the stability of the substance at room temperature. It was observed that there was no component separation of the substances if put in a room where the temperature was higher than the mixing one. The negative temperature change of

the fuel could be separating the phase caused by the density alteration of the aqueous butanol and gasoline. The decrease in the temperature could be adding the density of both substances to the volume that caused a contraction. The declining density rate of each substance still needs to be investigated since it was difficult to measure. The measurement of blended substance density is challenging compared to that of the individual material. Based on the data shown, however, it could be predicted and indicative that the aqueous butanol density decreased faster than that of the gasoline. It significantly influenced the phase separation to aqueous butanol and gasoline since the wet alcohol was settled at the bottom.

The question now is why the wet butanol dissolved entirely with gasoline only the specific composition without employing a synthetic surfactant. The butanol (C_4H_9OH) structure consists of the R- and -OH parts, in which the first is nonpolar and the second is the polar section. The wet butanol was bound electrically with water through the -OH sections located in both substances. The water contains a polar part whose positive area belongs to +H, and the negative part is generated by the -O atom, a proton deficiency. It can be described that butanol-water is united as an aqueous substance consisting of pure butanol and water. If it interacts with gasoline, the -R part of the butanol, whose property is polar, is binding with the similar property of the gas.

As mentioned previously, the butanol is bound with water electrically, causing the interaction with gasoline not to be balanced in terms of not all gasoline paired with wet butanol unless the water is present. This is why the wet butanol dissolved with gasoline in the exact compositions and depended highly on temperature. Though gasoline is well known as a nonpolar substance, it has a polar property called a partial charge caused by the electron’s motion periodically

in the molecule. If an electron is located in the outer orbit, the charge of the pole tends to be negative.

An essential thing observed in this study was that the increase in sample temperature after the stable emulsion was achieved would remain the same state of the solution for every butanol purity. Still, it was not observed at the lower temperatures. The stable emulsion at a specific temperature would also not change when the butanol was added to the solution. It was discovered that it was working for all the butanol concentrations. The separation occurred when the gasoline was added to the solution, which was influenced by the equilibrium state; the forces acting on both substances were zero and were interrupted. The addition of the gasoline changed the interaction from zero- to the gravity resultant, whereby it caused the aqueous butanol to rise to the below side.

Applying the wet butanol and gasoline in the heat engine could be possible by managing the stability of the emulsion during working. The separation occurred at lower temperatures, and the gasoline composition increased. The separation caused by the change in temperature is easy to overcome by controlling the temperature inside fuel tanks. The electronic instrument must be added to the engine functioning to maintain the temperature at a constant value. Meanwhile, the increase in the gasoline composition of the substance caused the phase separation to be slight. The boiling point of the butanol average is higher compared to that of the gasoline. This element data enhances that the stability of the wet butanol and gasoline inside the tank is constant with being required the temperature does not alter highly.

Fig. 4, 5 and Tables 4, 5 display the area of the substances that are either separated or dissolved employing aqueous butanol 96.00–99.50 % blended in at low temperatures. The solid circles describe the equilibrium state of butanol, gasoline, and water. The facts found that the increase of gasoline composition in the fixed temperature swiftly separated the substance into aqueous butanol and oil. The stability of the emulsion changed dramatically when the gasoline inclined, but it did not occur for the addition of butanol. Adding the gasoline broke the weak bonds between the positive and negative parts and the nonpolar ones.

However, the addition of the butanol continually after the stable emulsion was attained did not tend to the separation of the substance at any temperatures and butanol concentrations, which was comparable to the previous study employing aqueous ethanol [25]. Another analysis of this considered that the gasoline was distributed through butanol molecules, which seemed like a fence trapping the gasoline molecules. Adding butanol meant that the barriers added to block the gasoline kept inside the border. Adding gasoline after the equilibrium state was reached suggested that the gasoline spilled passing the fences of butanol.

The employing butanol 96.00–99.50 % blended with gasoline, whose temperatures was less than those in stable emulsion, started appearing white spots and separating the phase. The decreasing butanol purity is similar to adding the water content inside the emulsion. The bonds of the butanol and gasoline are a weak connection, which is fragile to external forces, such as gravity. It was observed that the emulsion at room temperature was not transparent, employing less butanol purities because of the higher water presence.

Generally, the temperature increased after the equilibrium state was formed, keeping the stability of the emulsion.

The temperature incline could be declining the density, but the bonds of the polar and nonpolar parts were not broken. The state could be analyzed that the gasoline molecules were trapped inside the butanol substances though the vibration and collision increased. The present study still needed to find the optimum temperature for separating the substances. The study also revealed that the temperature decline of the substance occurred during the phase separation, which could be observed clearly. The lower the temperature was set, the higher the density formed of the components. The bonds of the polar and nonpolar parts were disconnected, caused by the gravitational force. The weight of the aqueous butanol was more extensive than that of the internal interactions, which were the weak forces. The gasoline substance escaped upward of the space surrounded by aqueous butanol, which moved downward, which was comparable to the study reported previously.

As described previously, the butanol substance has two parts: polar and nonpolar. The dissolution of the water with gasoline was enhanced by the butanol functioning as a surfactant. The previous reports generally introduced a synthetic surfactant to dissolve the wet alcohol and the fossil fuels [26, 27]. Employing synthetic surfactants increased the cost of production, and it was not environmentally friendly since they were derived from nonrenewable substances [28, 29]. The present work was the new thing that the butanol itself was the surfactant and one of the components of the emulsion fuel. The finding, of course, decreases the cost of production of the blended fuels, especially those involving the butanol substance.

The equilibrium state in which butanol, gasoline, and water are in a stable emulsion employing butanol 96.00–99.50 % mixed at low temperatures as shown in Fig. 4, 5. As explained previously, the addition of the butanol continually after the stability was attained did not cause a phase separation. The area, which is a trapezoidal shape and located below the equilibrium line, is the stable state of the emulsion substance. It contains unlimited points of butanol, gasoline, and water in a stable liquid at a wide range of temperatures less than the room temperature. The present findings have yet to be reported by investigators in emulsion fuels. The increase of butanol purity shifted the equilibrium line where the aqueous butanol was just dissolved with gasoline uniformly. The change of butanol purity from less to higher purity declined significantly the amount of butanol added with gasoline to form a stable substance. It was caused by the reduction of the water content, and the gravity and polar interactions were dwindling, changed by a weak connection between -R of the butanol and gasoline molecule, dominated mainly by nonpolar branches. The maximum purity of 99.50 % only needed a fraction of the butanol, which meant that the non-polar interactions were dominating due to the absence of water in the large part.

The blended fuels obtained has still limitations which should be solved in order to the substances could be employed in the modified engine. The emulsions of the wet butanol and gasoline blended in the homogeneous solution could be separated into each component because of the temperature decrease, extremely as described. In practical application, the heat engine should be installed with an electronic device connected to the fuel tank to control the temperature

and equipped with a stirrer which would be developed by investigators in the coming works.

7. Conclusions

1. The compositions of pure butanol, gasoline (RONs 90), and water, which formed a stable emulsion at low temperatures, were successfully studied. It was found that the composition ranges are written as follows: a. Pure butanol 52.94–66.67 %; gasoline 25.93–41.18 %; water 5.88–7.41 % using butanol 90 % mixed at –0.50 to 27.30 °C, b. Pure butanol 20.86–52.80 %; gasoline 43.75–70.00 %; water 1.36–1.45 % employing butanol 93.86 % and being blended at –13.60 to 27.90 °C.

2. The stable emulsions were achieved with composition ranges of substances as follow: pure butanol 12.00–32.00 %; gasoline 66.67–87.50 %; water 0.50–1.33 % introducing butanol 96 % and being mixed at –8.40 to 27.30 °C and pure butanol 0.71–11.34 %; gasoline 88.61–99.29 %; water 0.01–0.06 % introducing butanol 99.50 % and stabilized at 0.00 to 29.00 °C. It was recorded that when the temperature declined after the emulsion was stabilized, the phases of the component were separated which was not observed with increasing of the temperature.

Conflict of interest

The authors declare that they have no conflict of interest concerning this research, whether financial, personal, authorship, or otherwise, that could affect the study and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

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