

Temperature-influenced Bulk Emulsion (BE) Demulsification Method as a PIBSA-MEA Emulsifier Durability Test in Blasting Environments under 100 °C

Gunaryo^{1*}, Anggito Budiman¹, Ratihlia Dhea Widyawati¹, Fidela Aurellia Salsabila¹,
Syahdan Al Gibran¹, Anggaria Maharani²

¹*Department of Chemistry, Faculty of Military Mathematics and Natural Sciences,
The Republic of Indonesia Defense University, Bogor 16810, Indonesia*

²*Department of Energetic Material Center, PT. DAHANA, Subang 41285, Indonesia*

Received: 2 Apr 2024; Revised: 23 Jun 2024; Accepted: 26 Jun 2024;
Published online: 30 Jun 2024; Published regularly: 30 Jun 2024

Abstract—This research attempts to provide a better method, examine more effective temperatures for testing emulsifiers, and determine the demulsification limit that indicates emulsifier durability. This experiment was conducted by varying the temperature (40, 60, 80, and 100 °C) for heating the product with a test time of 1, 2, 4, and 6 h, then detected using formaldehyde titration to determine the highest level of demulsification of ammonium nitrate (AN) salt at each temperature in the product. The results showed that 100 °C was the most effective and representative temperature for testing the durability of the emulsifier with the highest level of demulsification from the other temperatures. This was indicated by the weight of AN salt that came out of the emulsion reaching 2.05 g from 20 g of emulsion or about 10.25% of the total weight of the product within 6 h. Emulsifiers with AN levels below 2.05 g (10.25%) were considered to pass the test and could be used for further production or analysis. This new test method was expected that bulk emulsion manufacturers would be faster in eliminating PIBSA-base (Polyisobutylene succinic anhydride-base) emulsifier products widely used by emulsifier manufacturers in manufacturing BE. This was due to it only focusing on the ability of emulsifiers to hold the product in high-temperature exposure so that it remained unified and not demulsified.

Keywords— *Bulk Emulsion (BE); Demulsification; Emulsifier*

1. INTRODUCTION

Polyisobutylene succinic anhydride (PIBSA)-based surfactants are commonly used to render kinetic stability to high internal phase (HIP) water-in-oil emulsions [1]. This emulsifier helps to unite the emulsion in Bulk Emulsion (BE) explosives from the water-soluble oxidizer salt (ammonium nitrate) and the fuel in the form of oil. BE is a cap-sensitive explosive that comes from the union of the oxidizer and fuel by the emulsifier, sensitive to number 8 detonators, flowable and pumpable material that is easy to insert into the borehole, and has a VOD (Velocity of Detonation) around 4500–4800 m/s [2]. Emulsion explosives were first patented by Richard Egly and Albert Neckar in 1961 and first entered South African underground mining operations in cartridge form in the early 1980s [3]. Blasting with BE is also considered to be more efficient and capable of digging holes with less width and more

depth compared to excavators or other heavy equipment, which must dig holes from 6 to 12 meters wide [4].

Another advantage of BE is its water resistance and low gas emissions [5]. This is due to BE's water-in-oil emulsion form, which is water resistant, and the complete combustion produced by BE's detonation process with initiation from the primer. BE consists of an oxidizing solution (oxidizer salts such as ammonium nitrate and water) mixed with a fuel such as diesel and combined using an emulsifier to form a water-in-oil emulsion [2]. Emulsifiers are used to break up the rag layers that form in either slurry (O/W) or Emulsions (W/O) mixtures due to the interfacial tension formed between them so that these mixtures can be homogeneous [6]. Therefore, emulsifiers or emulsifying agents are needed in the manufacture of BE.

*Corresponding author.

Email address: gunaryo92000@gmail.com

DOI: 10.55749/ijcs.v3i1.44



Emulsifying agents commonly called emulsifiers function to unite the water phase, namely oxidation solution with fuels. Emulsions are formed from two elements or compounds that are hydrophilic and hydrophobic. Emulsions are formed non-spontaneously, where the kinetic stability of the emulsion is obtained from the balance of the repulsive and attractive forces of the particles. Emulsions used to unite oxidizers and reductants in explosives are generally those with HLB (Hydrophile-Lipophile Balance) values of 3-6 [7]. This is because they can form water in oil emulsions.

Emulsifiers, commonly used in W/O emulsions, are generally PIBSA-based (Polyisobutylene succinic anhydride) emulsifiers [2]. Determination of W/O or O/W emulsifiers can simply be done by dripping methylene blue and Sudan III. If the methylene blue solution is immediately dispersed throughout the emulsion, the emulsion is of the O/W type.

If the Sudan III solution is dispersed throughout the emulsion, the emulsifier used is of the W/O type [8]. Fig. 1 is an example of a PIBSA-based emulsifier. These emulsifiers have a unique structure, namely polar and non-polar which are hydrophilic and lipophilic. These two sides can bind two different phases (oxidizer and fuel) in the form of droplets resulting in water-in-oil- or oil-in-water emulsions.

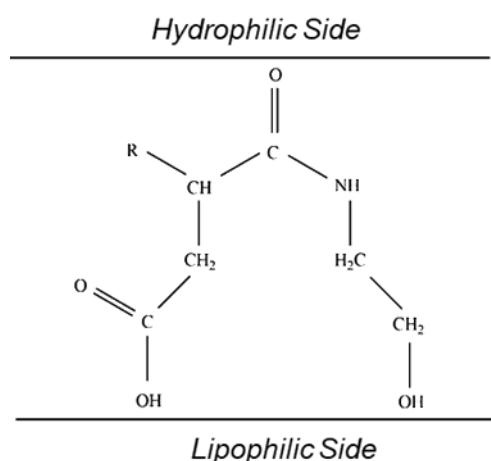


Fig. 1 PIBSA-MEA structure [9]

Emulsifiers have a specific elasticity capacity used to incorporate the oxidizer solution (oxol solution) into the emulsifier to form microdroplets. Thus, it can be dispersed into the fuel. The elasticity of each emulsifier is affected by pH, temperature, and mechanical treatment [6]. In its application, BE has a certain sleep time that affects VOD. Essentially, longer sleep times lead to lower VOD values [10]. This is determined by the OB (oxygen balance) contained in BE where an unbalanced number of molecules between oxidizers and reductants can decrease the VOD time [2]. The unbalanced number of molecules is the cause of all three factors. Thus, the oxidizer salt comes out of the emulsion, leading to the demulsification process.

One of the applicable laws on emulsifiers is the Gibbs-Marangoni Effect [6]. Fig. 2 illustrates the Gibbs-Marangoni Effect in an emulsion. The Gibbs effect occurs when an emulsifier with a specific surface tension undergoes expansion, resulting in the entry of liquid flow from the low-tension area to the high-tension area. Once adsorption occurs into the emulsifier droplet, the Marangoni effect acts as a surface tension reverser, causing an increase in surface tension. This increase provides increased resistance to further expansion.

PIBSA-based emulsifier used in BE manufacturing often comes from many companies. Testing these emulsifiers involves numerous parameters, including physical tests, durability, and emulsification. However, this test uses a large amount of emulsifier samples, which impact the effectiveness of the test, costing much money, and only paying attention to qualitative aspects. Meanwhile, samples continue to arrive from emulsifier factories. Thus, producers often have difficulty testing the proposed emulsifiers individually, resulting in lengthy testing times. Therefore, a quantitative testing method will be more effective and profitable because it can eliminate emulsifiers with a smaller number of samples and a shorter time. One solution is to determine a quantitative method using only one parameter, such as temperature, to demulsify salt in BE. This approach will enable producers to determine the level of demulsification in the emulsifier used. Thus, the limits set will be more controlled and increase the effectiveness and efficiency of the test.

Testing the durability and stability of emulsifiers with temperature can be done by disrupting the effects caused by the Marangoni effect law. The instability can be done by mechanical treatment or by increasing the temperature of the emulsion [6]. This causes further expansion of the emulsion resistance by the Marangoni effect. This will cause oxidizer salts, such as ammonium nitrate to come out of the emulsion, commonly known as demulsification. Thus, the ammonium nitrate, that comes out of the emulsion, can be calculated and becomes a parameter of emulsifier durability in bulk emulsion manufacture.

Emulsion stability tests can be carried out at various temperatures at room temperature of 25 °C and hot temperature of 40 °C by observing physical parameters (white crystals that come out of the emulsion) and pH stability [8]. Other temperatures that can be applied are 60 °C, which this temperature is the existing temperature in the borehole, and extreme temperatures of 100 °C [11]. In addition, emulsifier durability tests can also be observed and accelerate the demulsification process at temperatures of 80-90 °C, in which the active ingredients in the emulsifier at this temperature are most likely not functioning effectively [2].

The oxidizer salts that come out of the emulsion,

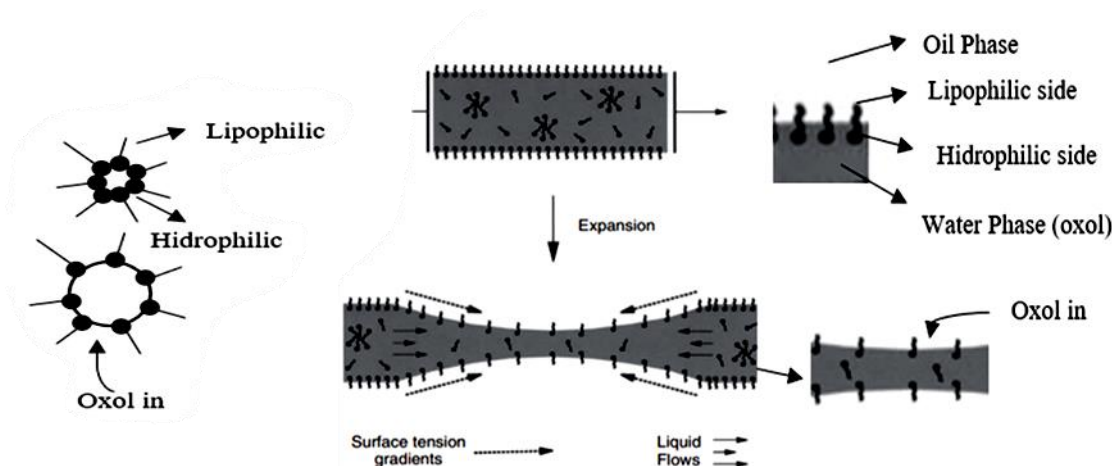
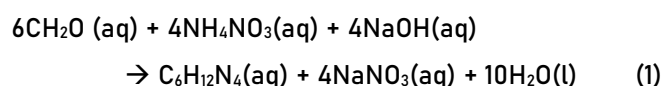


Fig. 2 Expansion of the emulsifier causes oxol droplets to enter and absorb [6]

such as ammonium nitrate used in BE, are dissolved in water to separate them from the emulsion. These salts can be detected using the acid-base titration method. This method determines the concentration of an unknown compound based on its acid and base parameters. The acid-base titration method is divided into two, acidimetry and alkalimetry. Acidimetry is used to determine the level of basic solutions using acidic raw substances, while alkalimetry is used to determine the level of acidic solutions using basic raw substances [10,11]. In our study to test the resistance of emulsifiers in BE, the alkalimetric titration method has been used to quantify the amount of ammonium nitrate oxidizer salt that comes out of the emulsion using basic raw material.

Alkalimetric titration using a strong base causes ammonium nitrate to demulsify from the emulsion as crystals. Dissolving these crystals in water results in a decrease in the pH or tend to be more acidic (salt hydrolysis). In this case, water-soluble ammonium nitrate content is then determined by the formaldehyde titration method. This method can determine the levels of ammonium nitrate and ammonium sulphate using formaldehyde with indicators, such as phenolphthalein or a combination of methylene red and methylene blue [12,13]. This method is commonly used for analyzing ammonium nitrate in explosives and fertilizers. The reaction between ammonium nitrate or ammonia and formaldehyde forms hexamethylenetetramine or hexamine (VI), as displayed in equation (1) [14].



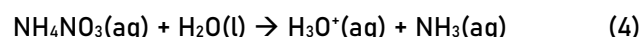
The titration reaction of ammonium nitrate determination can usually be carried out using formaldehyde in a preheated state at 60 °C. However, according to another source, titration can be carried out at room temperature, as indicated by the formula in equation (2)[15]. And if the analysis is concerned with the amount of ammonium nitrate (in grams) coming out of the emulsion, the result can be calculated using the

formula in equation (3). The 0.08004 value represents the gram weight of NH_4NO_3 per mole.

$$\% \text{ Nitrogen} = \frac{V \text{ NaOH} \times N \text{ NaOH} \times 2.8014}{\text{sample weight}} \quad (2)$$

$$\text{Total } \text{NH}_4\text{NO}_3 \text{ (g)} = \frac{\text{Net ml NaOH} \times N \text{ NaOH} \times 0.08004 \times \text{solvent}}{\text{amount of solvent water titrated}} \quad (3)$$

In addition, the amount of salt that comes out of the emulsion can also be determined using a pH measurement method. Ammonium nitrate is a salt formed by the combination of ammonium ions (NH_4^+) and nitrate ions (NO_3^-). Salts can be acidic, basic, or neutral, depending on the cation and anion constituents that contribute to it. Ammonium nitrate is a salt originating from a strong acid and a weak base, thus, it tends to be acidic due to partial hydrolysis [14]. Therefore, ammonium nitrate salts can be identified by reacting them with water and measured using a pH meter. The reaction between ammonium nitrate and water is shown in equation (4). The NH_4NO_3 salt components can be calculated using the formula shown in equation (5).



$$[\text{H}^+] = \sqrt{\frac{K_w \times [\text{NH}_4\text{NO}_3]}{K_b \text{ NH}_4\text{OH}}} \quad (5)$$

As the concentration of ammonium nitrate in the water solution increases, the concentration of H^+ ions also increases, leading to a decrease in the pH. This demonstrates a direct relationship between a decrease in pH and the increase in ammonium nitrate in the aqueous dispersion solution [16].

In microscopic observation, the emulsion also needs to be tested to observe changes in the emulsion in the form of droplets before and after heating. As ammonium nitrate is released, the number of droplets will also experience a decline. In addition, changes in droplet shape reduction, size homogeneity, and droplet number affect the emulsions demulsified by temperature or other mechanical influences [17].

Microscopic observations can be made using a microscope capable of magnifying objects up to 100× magnification. Observations of emulsion characteristics, such as the number and size of droplets, can be identified using a binocular microscope. In some studies, microscopic analysis in emulsions shows emulsion droplets where the smaller particle size of an emulsion indicates that the emulsion will be more stable. In this case, the application of microscopic tests was carried out to observe the results of bulk emulsion demulsification through the addition of ammonium nitrate crystals visually and to validate the demulsified salt.

2. EXPERIMENTAL SECTION

2.1. Materials

The tools used were burette, stative, 100 mL Pyrex Erlenmeyer flask, Memmert oven, large test tube (100 mL capacity), dropper pipette, Zeiss binocular microscope, Hanna Instrument pH meter, thermometer, and emulsion container. The materials used were bulk emulsion BE from PIBSA-MEA emulsifying agent with a capacity of 500 g, 37% formaldehyde (Merck), 0.1 N NaOH (Merck), phenolphthalein indicator (Merck), and distilled water.

2.2. Temperature Determination

The temperature determination was carried out by heating BE made by PIBSA-MEA emulsifier at 40, 60, 80, and 100 °C with the BE of 20 g each into a large test tube for 1 sample within 1, 2, 4, and 6 h, for a total of 4 samples each temperature in the oven. This means that at a temperature of 40 °C, 4 samples were removed gradually from the oven starting from 1, 2, 4, and 6 h, and the same applies to the following temperatures [2]. Then, after the specified time, individually, the samples were removed from the oven along with the test tubes. The test tube with BE in it was left to cool. Once cool, 200 mL of distilled water was added and allowed to stand for 2 h. After standing, 25 mL of water containing BE was taken from each sample and reacted with 10 mL of formaldehyde in a 100 mL flask. The samples were left for approximately 10 min [15].

Furthermore, the sample was dabbed with 5 drops of phenolphthalein indicator with a dropper pipette and titrated with 0.1 N NaOH solution to obtain the number of grams of ammonium nitrate, coming out from the emulsion. Finally, a 50 mL BE water sample from each of the remaining samples was also tested for pH with a Hanna Instrument pH meter to ensure that the pH value of the water had decreased from that of the water that had not been put into the BE. The method was to take the BE sample and test it using a previously calibrated pH meter. The calibration used standards of pH 7 and 4. Then, testing was carried out directly on BE water samples. Thus, the number of grams of ammonium

nitrate could be obtained, and the results were plotted against heating time for each temperature (40, 60, 80, and 100 °C). Thus, one gradient could be selected to determine the test.

Statistical data processing for pH and demulsified ammonium nitrate used Microsoft Excel for graphical processing. The basic principle is plotting the x and y axes, where the x-axis is time, and the y-axis is the amount of demulsified ammonium nitrate and pH value. Plotting was achieved by blocking the x-axis and y-axis. In the insert menu, there is a scatter-type chart bar that can be clicked to generate the desired graph. Text changes in the x-axis, y-axis, and title can be made by double-clicking and editing the text. Thus, this process allows for the creation of the graph

2.3. Microscopic Testing of Temperature Variations on Emulsion Morphology

Morphological testing of emulsions at various temperatures was carried out using a Zeiss binocular microscope coupled with a digital computer. The samples observed were BE samples at each temperature (40, 60, 80, and 100 °C) which were heated for 6 h. Thus, at that time the salt was optimally demulsified in each method, and the demulsified salt could be observed at each temperature. The first step was to switch on the computer and install the ZEN software. Subsequently, the microscope was connected to the computer and plugged in with the available cable. Then, the ZEN application was opened by selecting the "Run as Administrator" option after right-clicking on the ZEN icon to launch the application with administrator permissions. Furthermore, the microscope was switched on by pressing the switch at the bottom to turn on the microscope. Once the ZEN application was opened, clicking on the "real-time" section allowed to monitor the sample in the connected microscope.

The microscope, that had been lit, was adjusted to a level that suited the light conditions in the room and set at 100 × magnification before proceeding with sample preparation. The glass prepared for sample observation was cleaned first using acetone. Subsequently, the sample was scratched as thin as possible onto the glass covered with another glass again, and clamped using a glass clamp on the microscope. The coarse and fine rotators were rotated to produce a focal point on the sample. Once the focal point was achieved, the image was 'snapped' and saved to the PC.

Statistical data processing was processed using Microsoft Word. The captured image saved on the PC was then opened in Microsoft Word. The image was observed visually to identify the demulsified ammonium nitrate (appearing white in the capture results). The results of the visual review were then marked with a circle shape in the insert and shapes menu. Then, the marker adjustments could be modified using the shapes format and changing the fill and outline. Finally,

the image could be saved on the PC using the "Save As" menu and selecting the desired storage location.

3. RESULT AND DISCUSSION

3.1. Emulsifier Testing Method with Temperature Variation

Emulsifiers used in the manufacture of BE have a certain sensitivity to mechanical treatment, pH changes, and temperature fluctuations [5]. Tests often carried out on BE, are with the effect of pH and mechanical treatment on the emulsion. However, the emulsifier resistance here has not been tested using the temperature effect, despite temperature being an important parameter for demulsification. Temperature is a crucial parameter where BE storage also has a certain temperature or when BE is inserted into the bore hole and BE has a certain sleep time that will impact on the resulting VOD. Bore holes also have different temperatures, ranging from 55 to 100 °C in extreme temperatures. Therefore, this study aims to investigate the effects of temperature variations on BE to assess the durability of the emulsifying agent.

The materials were tested with temperature variation as the independent variable. Four reference temperatures were used: 40 °C for thermocycling (ageing test) or close to tropical temperature, 60 °C for ordinary borehole, 80 °C as the emulsifier ineffectiveness temperature according to Koch (2012) [2], and 100 °C for extreme borehole BE was weighed as much as 20 g for each sample and heated in an oven to heat BE even. Furthermore, the BE will be demulsified due to the effect of the emulsifying agent effect, the Marangoni-Gibbs Effect, where the emulsifier will stretch, and if the strength of the emulsifier bond is not strong, it will release crystalline ammonium nitrate out of the emulsion, which is indicated by the presence of white crystal patches on the emulsion surface.

Ammonium nitrate released from the emulsion surface will be dissolved or soaked into water by direct contact with the emulsion. After an optimum time of approximately 2 h at room temperature, ammonium nitrate will dissolve in water more completely. The ammonium nitrate solution was then separated from the emulsion to check the pH and ammonium nitrate (AN) levels in the solution. The pH check was carried out using a Hanna Instrument pH meter and testing of pH levels using formaldehyde titration. The pH measurement indicates the acidity of the solution containing AN while the formaldehyde titration determines the level of AN from the reaction with certain reactants.

Theoretically, the reaction produces hexamine(VI) and salt [18]. If NaOH is added excessively to the reaction, this can trigger a pH change above 7, turning the phenolphthalein indicator, from pink to purple. This color change indicates that NaOH no longer reacts with AN, signaling that AN has finished reacting. Thus, the

AN content can be determined according to the level of NaOH and formaldehyde reacted. In addition, changes in pH indicate the presence of AN in the emulsion soaking water solution, thus, it will result in a significant decrease in pH levels.

In Fig. 3a, it was found that the demulsified ammonium nitrate increased significantly when heated in all temperature variations. This is in accordance with other experiments, in which increasing temperature causes more ammonium nitrate salt to demulsify [19]. Of all the variations tested, the highest value was 100 °C. The highest temperature used to test bulk emulsion demulsification for 6 h, and its so representative of the mine environment [19]. Fig. 3a reveals that at 40 °C demulsification of ammonium nitrate increases over time: 0.33 g (1.7%) with a test time of 1 h, 0.38 g (1.9%) with a test time of 2 h, 0.39 g with a test time of 4 h (1.95%), and 0.40 g with a test time of 6 h (2%).

Temperature of 60 °C, it demulsifies ammonium nitrate as much as 0.36 g (1.8%) with a test time of 1 h, 0.40 g (2%) at 2 h, 0.76 g at 4 h (3.8%), and 0.86 g at 6 h (4.3%). At 80 °C, it demulsifies ammonium nitrate as much as 0.51 g (2.5%) with a test time of 1 h, 0.61 g (3.05%) at 2 h, 0.62 g at 4 h (3.1%), and 0.76 g at 6 h (3.8%). At 100 °C, it demulsifies ammonium nitrate as much as 0.87 g (4.3%) with a test time of 1 h, 1.93 g (9.65%) at 2 h, 1.99 g at 4 h (9.95%), and 2.04 g at 6 h (10.2%).

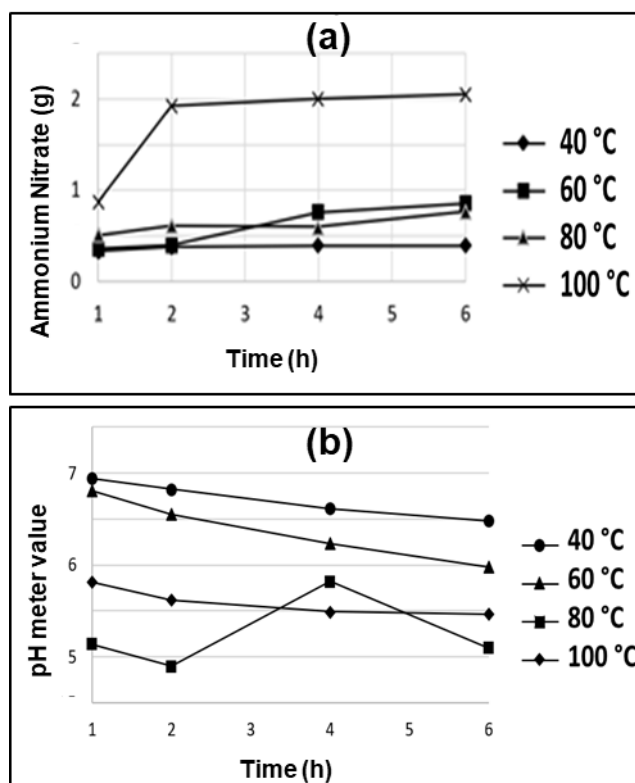


Fig. 3 (a) Graph of ammonium nitrate demulsified against temperature variation, (b) Graph of pH meter numbers against demulsification temperature variations

Fig. 3b confirms the trend: higher temperature leads to pH meter readings. This can be observed from the increasing amount of ammonium nitrate salt coming out from the emulsion. This is marked by the decreasing pH value in **Fig. 3b** for each emulsion batch solution at the applied temperature. This is a sign of the success of temperature in demulsifying the emulsion. The increase in the amount of emulsified ammonium nitrate, which results in a decrease in pH, is also in accordance with other research [16]. Therefore, pH can be used as a parameter to monitor the amount of salt demulsified from the BE product.

At 40 °C, the product was demulsified. This is indicated by the influence of the pH values, 6.94 in a test time of 1 h; 6.82 at 2 h; 6.61 at 4 h; and 6.48 at 6 h. Conversely, at 60 °C, the product emulsified. This is indicated by the influence of the pH values, 6.81 in a test time of 1 h; 6.55 at 2 h; 6.23 at 4 h; and 5.98 at 6 h. At 80 °C, the product emulsified as indicated by the influence of the pH values, 5.14 in a test time of 1 h; 4.9 at 2 h; 5.82 at 4 h; and 5.1 at 6 h. At 100 °C, the emulsified product as indicated by the influence of the pH value was 5.81 in a test time of 1 h; 5.62 at 2 h; 5.49 at 4 h; and 5.46 at 6 h. Even, pH values are caused by AN because the relatively more complex pH meter reading includes all pH in the emulsion bath water environment, which not only comes from AN but also the condition of distilled water and the acidity of the air in the environment, which can also affect the instrument.

Among the four products tested, the one exposed to a temperature of 100 °C had the shortest time when demulsifying ammonium nitrate from the emulsion with the weight of AN up to 2.05 g within 6 h and 5.46 for pH value. Thus, it is more efficient in the use of time and proves that it can demulsify AN with a greater amount. Then, a temperature of 100 °C was used to further test the emulsifier with the limit of demulsification at 6 h must be under 2.05 g per 20 g products or 10,25% per product. This is because it can effectively and efficiently demulsify the AN in the emulsion and is a representative temperature of a borehole with extreme heat.

3.2. Emulsions Morphology

In addition to the research conducted using formaldehyde titration, microscopic visual observations must also be considered to provide clear evidence of AN demulsification that comes out of the emulsion in the form of micro-sized crystals. In the microscopic results, **Fig. 4a** shows the condition of the emulsion before it is demulsified using temperature. The spherical shape of the emulsion confirms that the emulsifying agent has successfully combined the oxol and fuel solution into an emulsion form of BE. This is in accordance with the BE shape from other studies, namely a tightly rounded shape [20], which indicates that the emulsion process is going well.

The results of demulsification at 40 °C are shown in **Fig. 4b**. The previous emulsion was only in the form of balls, turning into an emulsion with black and white stains like crystals in the emulsion. This indicates that AN crystals are the result of demulsification, such as the morphology of BE crystals from other studies, which when observed microscopically will produce a type of white crystal, where the crystal are demulsified salt crystals [11]. **Fig. 4c** shows the emulsion in the demulsification results at 60 °C, where white crystal stain spots increase.

Similarly, **Fig. 4d** shows the results of demulsification at 80 °C, and **Fig. 4e** shows the results of demulsification at 100 °C, where the number of AN crystals increases. Thus, it can be concluded that temperature affects greatly the ability of the emulsifiers. The binding force caused by the elasticity of the emulsifier due to the influence of temperature can be reduced to break up, causing AN demulsification to form white crystals. These crystals will gradually enlarge and can be observed visually using a 100× magnification binocular microscope. Thus, the results of this demulsification are proven by analysis using a microscope.

These white crystals indicate ammonium nitrate coming out of the emulsion due to the effect of heating

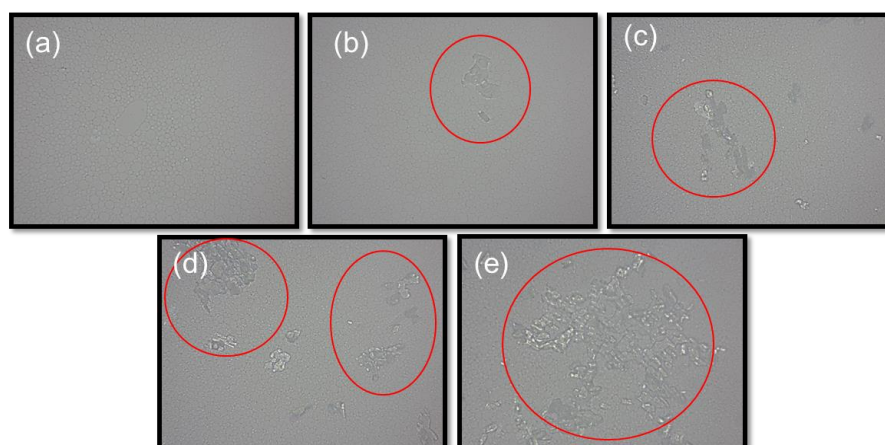


Fig. 4. Emulsion morphology of (a) before, (b) after 40 °C, (c) after 60 °C, (d) 80 °C, and (e) 100 °C temperature resistance testing from 6 h heating at each

variation. The heating variation on the emulsion shows a growing visibility of AN as the temperature increases [21]. This phenomenon can be attributed to a decrease in the surface tension of the emulsion, leading to cavity formation. These cavities allow AN to escape the emulsion, manifesting as an increasing number of white crystals.

CONCLUSION

The method of testing the durability of emulsifiers in Bulk Emulsion (BE) products could be achieved through heating at 100 °C. This test can be a representative test of the blasting environment and help test more quantitatively. Based on experimental data, the established test range through the experiment found that the test range of the formaldehyde titration test at 100 °C for 6 h was 2.05 g/ 20 g of emulsion or about 10.25% and decrease value of pH until 5.46 of the overall product mass. This decision was based on the longest tested time, namely 6 h, which produced the most demulsified salt, and the highest tested temperature of 100 °C, which also produced similar results.

Emulsifiers with levels below this mass or product demulsification percentages were considered to pass the test and could be used for the production process or further analysis. Conversely, emulsifiers with demulsification levels above the mass of the test range failed the test. This is because it causes too much salt demulsification that will cause oxygen imbalance and can impact the VOD of the product.

Although overall a new method has been discovered to analyze the ability of an emulsifier to maintain BE, several improvements to the method must continue to be updated for the benefit of the future. This cannot be separated from the shortcomings of this study, namely several technical errors in measuring pH at 80 °C, weighing errors, and the level of precision when making the solution. Therefore, further research can validate a better method if the borehole temperature is above 100 °C. Several other updated methods are also needed for this method to complete all aspects of testing the resistance of the emulsifier in maintaining the emulsion. Thus, the method of selecting the ability of the emulsifier to withstand demulsification will be more effective and efficient with materials and tools that are relatively cheap and widely available on the market.

SUPPORTING INFORMATION

There is no supporting information in this paper. The data that support the findings of this study are available on request from the corresponding author (Gunaryo).

ACKNOWLEDGEMENTS

The author(s) highly acknowledge Department of Chemistry, The Republic of Indonesia Defense

University and PT. DAHANA for supporting the tools and resource.

CONFLICT OF INTEREST

The authors have no conflict of interest in this publication.

AUTHOR CONTRIBUTIONS

Gunaryo and AB performed the experiment and wrote the early manuscript. Gunaryo, AB, RDW, FAS, SAG, and AM collaborated on data calculations, writing, and revising the manuscript. All authors agreed the final version of the manuscript.

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