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Role of Intermolecular Force on the Instability of Absorption and Release of Heat in Kapok Oil

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Abstract: This study aims to experimentally determine the role of intermolecular forces on the instability of absorption and release of heat in Kapok oil. Heat absorption and release were measured using a Differential Sanning Calorimeter (DSC). The thermogram shows that heat absorption and release are unstable. The results indicate that the during the first cooling process, there is a shoulder visible in the thermogram which is caused by a separation between the molecules in the Kapok oil. The longest molecule has the most energetic Van der Waals interaction. The Van der Waals interaction exists even when the vibration of the molecule becomes weak. Therefore, a long particle attracts another long particle and a short particle attracts another short particle. The separation causes the instability of heat absorption and release.

INTRODUCTION

Phase Change Material (PCM) uses energy released or absorbed from the repository for energy storage. The postulant for PCM, generally, consists of chemical compounds that contain carbon and chemical compounds that lack C-H bonds. A compound that requires C-H bonds encloses salt hydrates, salts, metals and alloys. The chemical compounds that lack C-H bonds are divided into paraffin and non-paraffin that is fatty acids, esters, alcohols and glycols[1]. Some of the materials do not satisfy the requirements for an adequate PCM appliance. Therefore, the prepared materials used and their thermophysical characteristics are to be ready in advance[2]. The requirements for appropriate PCM are agglomerated into carnal, engineering and economical. Circulation consistency is a carnal compulsions which is based on the keeping and removal of heat[3].

Currently, the use of vegetable oil is increasingly widespread. In addition PCM vegetable oil has been researched and developed into lubricating oil. Although, some types of vegetable oil have low stability, especially at low temperatures, several studies have proposed the use of vegetable oils as a substitute for commercial minerals or synthetic oils, both pure and modified. One of the requirements for developing vegetable oil is thermal stability[4].

It is essential to understand the thermal behavior of vegetable oils, their chemical composition, and physical properties for process control and to set standards for each specific use. Specific heat Capacity (Cp) is considered essential physical property. Knowledge of the specific heat capacity of oils and fats is sufficient to determine their behavior during different technological processes[5]. Heat vital property of vegetable oil which significantly influences the temperature bondage of essential thermodynamic functions[6] is also a primary characteristic of the thermophysical response of molecules in addition to thermal energy[7].

The Melting Point (MP) of a material is one of its most decisive physical attributes. It plays a significant role in determining the suitability and applicability of a substance[8]. Research has indicated that the thermal consistency of oil upon heating depends on the fatty acid composition. The matter of the vegetable oil influences the condition of the oil[9]. Vegetable oil could be modified to obtain the desired terms as well as thermal consistency. The most direct and economic technique for changing the characteristics of edible oil is to mix it with different oils which can alter the fatty acid content of the product[10].

Properly blending fats from various vegetable oils can improve the functional parameters of the final product. For example, the addition of palm oil olein, olive oil and corn oil to canola oil increases thermal stability[10].

However, there are several types of vegetable oil available. Kapok oil is a type of fat that is widely produced in Indonesia but has not been extensively studied including its thermal stability. Therefore, in this study, the thermal stability of Kapok oil in a repeated heating-cooling process is analyzed which will initiate the study of mixing Kapok oil with other vegetable oils.

MATERIALS AND METHODS

The Kapok oil was purchased from the local market. Its chemical constituents tested by gas chromatography are listed.

The heat capacity of Kapok oil was quantified using a Differential Scanning Calorimeter (DSC) which was used to measure the energy needed to increase the specific transformation in the temperature of a unit mass of the substance. The DSC quantified the specific heat capacity by warming a specimen and measuring the temperature distinction between the sample and a matrix. For many years, the DSC results of oils and fats have provided a useful explanation regardingon melting and crystallizing temperatures as well as heats of fusion and crystallization. This method has been used to observe the phase behavior of TAG blends, to assess the influence of minor parts on the crystallization of oils and fats to monitor polymorphic transformations in edible oils and fats and for observing failed-batch palm oil[11].

A DSC Perkin Elmer 800 was used it is a double-furnace and power-compensation DSC. The purging gas used N2 with a flow rate of 20 mL min^{-1}. The oil sample was heated from a starting temperature of approximately 30-13°C. Following the heating process, the sample was cooled to approximately 30°C, heated again to 13°C and cooled back to -30°C. The result of the process is presented in a thermogram which exhibits the thermal characteristics of Kapok oil.

RESULTS AND DISCUSSION

First, the fatty acid composition of Kapok oil was investigated. Based on the testing results, Kapok oil contains 56-55% linoleic acid ($C_{18}H_{32}O_2$) which acid is a monoun saturated fatty acid as two double bonds and 18 carbon atoms within its molecule (Fig. 1).

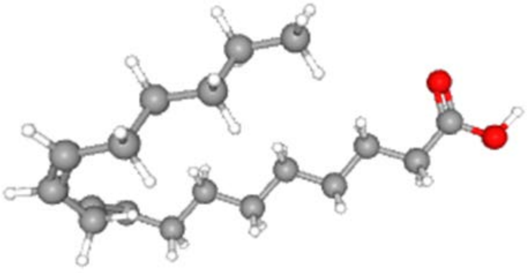
Fig. 1: Lnoleic acid

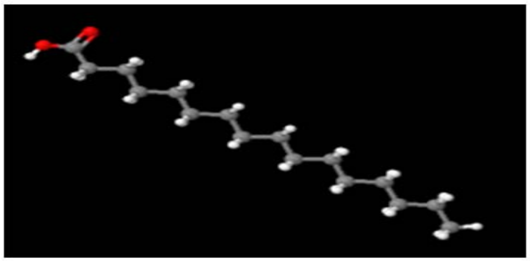
Fig. 2: Palmitic acid[19]

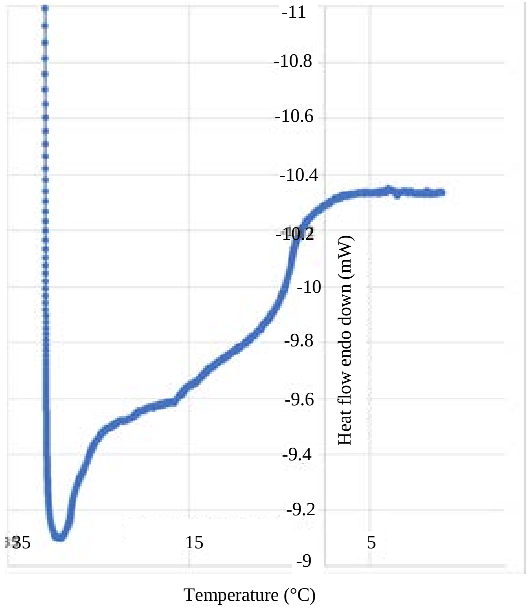

Fig. 3: First heating thermogram

Kapok oil contains 21-01% of palmitic acid ($C_{16}H_{32}O_2$) which is a saturated long-chain fatty acid with a 16-carbon backbone. Palmitic acid is found naturally in palm oil and palm kernel oil as well as in butter, cheese, milk and meat[12] (Fig. 2 and Table 1).

Figure 3 shows that no peak is observed as the temperature increases from -30-13°C. The lowest

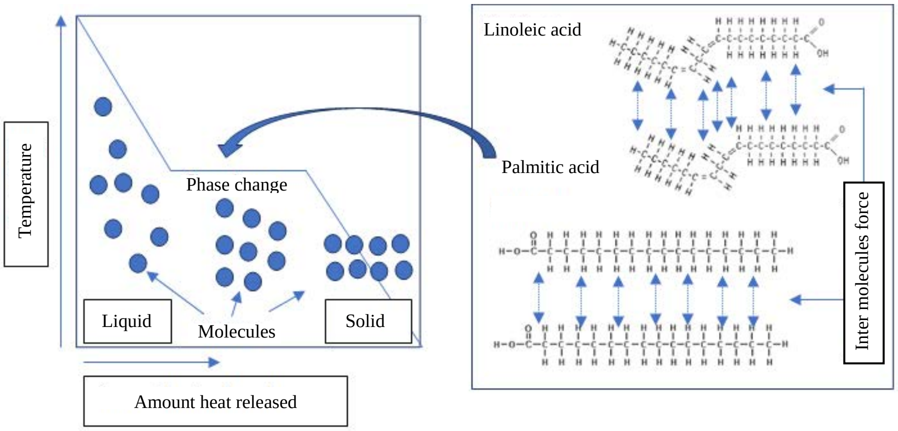

Fig. 4: Intermolecular force on the phase change

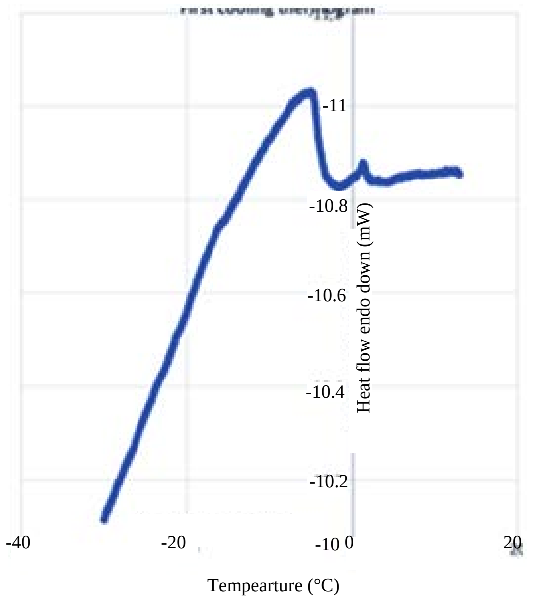

Fig. 5: First cooling thermogram

Table 1: Chemical constituent of Kapok oil

Fatty acid	Percentage
$C_{18}H_{32}O_2$ (Linoleic acid)	56.55
$C_{16}H_{32}O_2$ (Palmitic acid)	21.01
$C_{22}H_{40}O_2$ (Docosadienoic acid)	8.27

heat flow recorded was at -9.10217 mW at a temperature of -29.546°C to round to -9.47 mW at a temperature of -24.79°C. The change in heat flow causes an increase in slope and 10.31 mW at 1.7°C. Furthermore, the heat flow is almost unchanged which is -10.33 mW at 13°C.

This is because vegetable oils still mix (no separation occurs). The addition of high heat energy when the latent heat absorbed is not visible.

Phase changes are also settled by the interaction between kinetic energy and the intermolecular forces the temperature rises, the average kinetic energy rises as well, so the faster mobile particles can beat out attractions more efficiently. On the other hand, cooler temperatures allow the forces to draw the slower mobile particles together[13]. The peak occurs due to high heat absorption which increase the temperature (latent heat). High heat absorption is required for strong intermolecular bonds. During preheating, the molecules are still homogeneous (no fractionation occurs), so that, there are no molecular bonds (intermolecular force) that are strong enough and require high heat absorption (Fig. 4 and 5).

A freezing process occurs in the first cooling episode of Kapok oil (from 12-30°C). The recorded heat flow was -10.859 mW at 12.45°C. The change to -10.838 mW at 2.437°C was not significant. Then, it changes to -10.872 mW at 1,058°C followed by it will change to -10.826 mW at -1.805°C -11.02 mW at -4.79°C and down to -10.11 mW at -29.98°C.

In this process, the molecules move more slowly so that they get a fixed position[13]. This process is exothermic the system loses energy which is released in the form of heat. The occurrence of a peak in the cooling process is due to of crystal formation[14]. The formation that occurs differs during heating, causing irregularities. The causes of capriciousness are diverse. Refining substances based on differences in their solubility may lead to the emergence of crystallization exotherms with several culminations[15].

Considering the separation process, the molecules are first mixed. Molecules have intermolecular forces. At room temperature, the vibrational molecules vibrate a decrease in temperature, weakens the vibration. When vibrations become weaker, intermolecular forces still work, strengthening the attraction between molecules. Longer molecules have stronger attractions. Linoleic acid which comprises 56.55% of the Kapok oil components, attracts its own molecules to each other llikewise for the other constituent elements (Fig. 6).

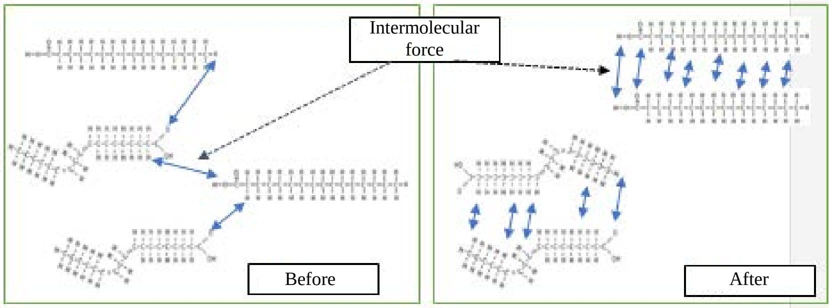

Fig. 6: Intermmolecular force on separation

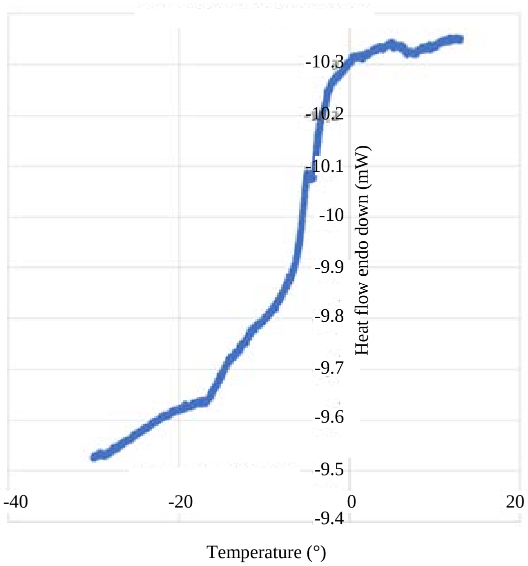

Fig. 7: Second heating thermogram

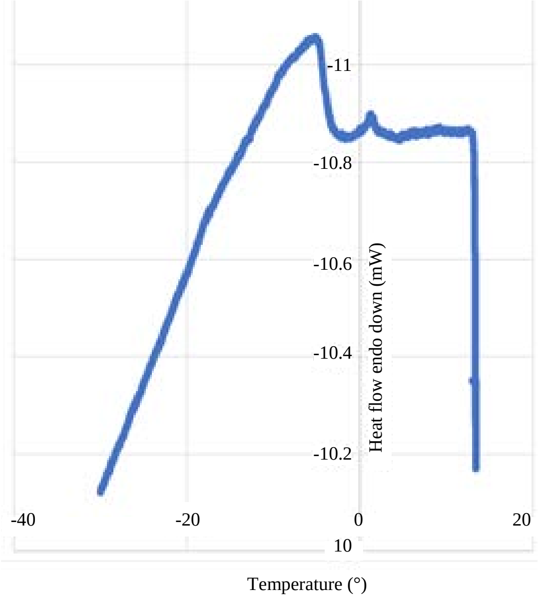

Fig. 8: Second cooling thermogram

The level of unsaturation has the most significant influence on separation. The existence of double bonds in TAG decreases its retention time on the column[1]. TAGs were parted following their level of unsaturation and molecular heaviness. Separation is the removal of solids at specific temperatures. The most widely experienced form of fractionation is that of crystallization wherein a blend of triglycerides is separated into two or more different melting fractions based on solubility at a given temperature[16, 19].

Kapok oil consists of Linoleic Acid, 56.55%. Linoleic acid is a $C_{18}H_{32}O_2$ monounsaturated fatty acid. Kapok oil also consists of 21.01% palmitic acid. Palmitic acid is a saturated long-chain fatty acid. Palmitic acid freezes at higher temperatures than linoleic acid. Saturated fatty acids have a higher freezing point than an unsaturated fatty acids.

Figure 7 presents the results of the temperature increase from -30 to 13°C. A peak that occurs at 3°C indicates a change in palmitic acid to freezing conditions. The melting points of unsaturated fatty acids are considerably lower than those of saturated fatty acids with the same number of carbon atoms (Fig. 8).

The peak that occurs at -5°C indicates the freezing of linoleic acid. The melting point of unsaturated fatty acids is much lower because the configuration produces a bend in the structure which decreases the number of possible Van der Waals interactions between molecules. For a given the fatty acid chain dimension, saturated fatty acids will have a higher melting temperature than those that are unsaturated.

The temperature at which solid melts is referred to as the melting point and it depends on the strength of the cohesive forces of the atoms or molecules that compose it. The stronger the force the higher the melting point[17]. Under crystallization conditions intermolecular attractions move over the molecules around one another. Starting with the slowest, the molecules miss potential energy and arrange themselves into the crystalline structure of ice. Molecular motion continues but only as a result of the shaking of atoms about their existing positions[16].

At a temperature of -29-98°C, the heat flow was recorded which was equal to -9.524 mW followed by an increase to -10,075 mW at -5.05°C. It again decreases to -10.058 mW at -5.188°C and increases to -10.33 mW at 4.72°C. Furthermore, the recorded heat flow showed a decrease to -10.32 mW at 6.712°C and at approximately 12.4°C, the heat flow was recorded ast -10.348 mW.

At approximately-5°C, a small peak which resembles a shoulder occurs. The shape of the thermogram is different from that of the first heating thermogram. Thistrend proves that peak splitting behavior has occurred, indicating the immiscibility of the blends[18].

During the second cooling (from around 15-30°C), the thermogram formed is approximately the same as the first cooling thermogram.

In the second cooling process, the heat flow at a temperature of 12.04°C was recorded which was equal to -10.863 mW. After cooling to 3,51°C, the heat flow decreases to -10.85mW. At a temperature of 1.11°C, the heat flow was recorded ast -10.89 mW which was followed by a slight decrease the heat flow to -10,85 mW at -2,355°C and then an increased to -11,05 mW at -5,842^{o}C. Furthermore, it continued to decline to -10,121 mW at -29,9°C.

Separation occurs despite the increase in as indicated by the peak at -5°C which is higher than that of the first cooling thermogram. This indicates that more heat is released and an increasing number of linoleic acid contents are separated.

CONCLUSION

Our study has proven that the intermolecular force influences heat absorption of Kapok oil. The intermolecular force causes molecular separation. The intermolecular force that works is the Van der Waals force and it is not the same for every molecule. Longer molecules have more potent Van der Waals forces. During cooling, molecular vibrations weaken but the Van der Waals force still works. Thus molecules of the same size attract each other apart from molecules of shorter size. The separation of molecules causes instability in the thermogram of the repeated cooling process of Kapok oil. The uncertainty indicates non-uniform phase changes in the constituent molecules of vegetable oil.

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