

THE PHYSICAL STABILITY OF COCONUT MILK EMULSION

Alwani Hamad

Department of Chemical Engineering, Faculty of Engineering,
Muhammadiyah University of Purwokerto
Jl. Raya Dukuh Waluh PO BOX 202 Purwokerto
Email: hamadalwani@yahoo.co.id

Abstract

Coconut milk, a term for the aqueous extract from coconut solid meat, is often used in Asian cuisines as well as other part of the world. Studies to investigate the stability of the coconut milk emulsion often report inconsistently. The information about the stability of the coconut milk emulsion literature is used to keeping quality of coconut milks extract in processing and preservation (particularly by canning, spray-drying and freezing) and new food uses coconut milk.

Key word : Coconut milk, Stability emulsion, droplet size, coconut

I. INTRODUCTION

Coconut milk is generally applied to the white, opaque protein oil water emulsion obtained by pressing grated or comminuted solid coconut endosperm, with or without addition of potable water or liquid endosperm (coconut water). The emulsion is known to be naturally stabilized by coconut proteins: globulins, albumin and phospholipids. Such emulsifiers aid into the process and help to convert a high fat in coconut milk to flowable, but cohesive, powders through encapsulation of the fatty substance (Seow and Gwee 1997). Although in fact that the coconut milk is an indispensable ingredient in many Asian countries such as Indonesia, the information on its emulsion stability is comparatively sparse and widely scattered. The information should prove most useful to researchers as well as food processors.

II. COCONUT MILK EMULSION

Coconut milk is an indispensable ingredient in the traditional South East Asian cuisine and also a main component in the local kitchen in other parts of the world, for example Africa (Seow and Gwee 1997). Coconut milk is aqueous extract of the solid coconut endosperm, a white opaque protein-oil-water emulsion.

This liquid is obtained by pressing grated solid coconut endosperm, with or without addition of water or liquid endosperm, referred to as coconut water. Coconut milk is an emulsion and not physically stable. It separates into a cream and serum layer within 5 to 10 h after production (Seow and Gwee 1997; Gundberg 2008; Tangsuphoom and Coupland 2008). Home preparation of coconut milk usually involves the squeezing by hand of the freshly grated coconut meat, wrapped within a cheese cloth, to express "the milk". It is customary to repeat the extraction twice or thrice by adding water at room temperature, each time obtaining a more dilute milk (Seow and Gwee 1997).

The chemical composition of coconut milk shows variations due to differences in factors such as geographical location of the nuts, the maturity of the nuts, the method of extraction and the degree of dilution if water or liquid endosperm is added during extraction (Seow and Gwee 1997). The proximate composition of coconut milk as reported by different sources is summarized in Table 1.

Table 1 Proximate composition of undiluted whole coconut milk as reported by different sources (Seow and Gwee 1997)

Constituent (%)	Nathaneal (1954)	Popper et al. (1966)	Jeganathan (1970)	Anon.(1984) (Univ of Minn.)
Moisture	50.0	54.1	50.0	53.9
Fat	39.8	32.2	40.0	34.7
Protein (Nx 6.25)	2.8	4.4	3.0	3.6
Ash	1.2	1.0	1.5	1.2
Carbohydrate	6.2	8.3	5.5	6.6

Further (Seow and Gwee 1997) says that coconut milk contains carbohydrates, mainly sugars and starch, and minerals, such as phosphorus, calcium and potassium. The dominating proteins in coconut milk are albumins and globulins, and the protein content of the undiluted milk ranges from 5 - 10% on dry basis, but when the milk is filtered only about 30% of the protein is dissolved in the aqueous phase.

III. CHARACTERISTIC OF COCONUT MILK EMULSION

An emulsion is a mixture of two immiscible liquids, with one (a dispersed phase) presents as small spherical droplets in the other (a continuous phase). Emulsions are thermodynamically unstable due to the unfavorable contact between oil and water molecules, and as a consequence their physical structures will tend to change over time by various mechanisms (e.g., creaming, flocculation, and coalescence), eventually leading to complete phase separation. Kinetic stability over the lifetime of the product is usually achieved by the addition of proteins or small-molecule surfactants (McClements 2005).

Coconut milk is a natural oil-in-water emulsion extracted from the endosperm of mature coconut (*Cocos nucifera* L.) either with or without the addition of water (Seow and Gwee 1997). Food emulsions system such as coconut milk is thermodynamically unstable because of their interfacial tension. This leads to coalescence of dispersed phase droplets. As the droplet approach each other due to relative motion brought about by Brownian and gravitational forces, they are attached to each other by Van Der Waals force. In the absence of any stabilizer, dispersed phase droplets coalesce. This process is called phase separation and limits the shelf life of the coconut milk due to the spoilage (Jena and Das 2007).

A stabilizer is any ingredient that can be used to enhance the stability of an emulsion and may be classified as emulsifier or a texture modifier depending on its mode of actions:

III.1 Emulsifier

Emulsifier is surface active molecule that absorb to the surface of freshly formed droplets during homogenization, forming protective membrane that prevent the droplet from close enough together to aggregate (McClements 2005). The effective emulsifiers should have the following the general characteristics; first, it should be capable of rapidly adsorbing to the surface of freshly formed droplet during homogenization, second, it should be capable of reducing the interfacial tension by a significant amount, third, it should be capable of forming an interfacial membrane that is either resistant to rupture and/or provides a sufficiently strong repulsive interaction between the droplets (Dickinson and Golding 1997; McClements 2005). Food manufacturers usually measure and compare the functional properties of emulsifiers in term parameters that depend on the processing procedure and formulation of their actual food product (McClements 2005), for example :

- The minimum droplets size that can produced by a certain amount of emulsifier for a specified emulsion system using specified homogenization condition.
- The minimum amount of emulsifier required to produce a desired droplet size for specified emulsion system using specified homogenization condition.
- The long term stability (e.g. to creaming, flocculation, or coalescence) of a specified emulsion system produced by the emulsifier using specified homogenization condition.
- The above approach is particularly suited for food manufacturers trying to determine the best emulsifiers for usage in their specific product, but it is not particularly suited for development of the general classification scheme because of the wide variation in the composition and processing of different foods

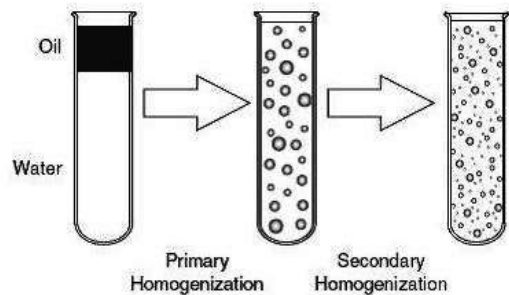


Figure 2 Homogenization can be conveniently divided into two categories: primary and secondary homogenization. Primary homogenization is the conversion of two bulk liquids into an emulsion, whereas secondary homogenization is the reduction in size of the droplets in an existing emulsion (McClements 2005)

III.2 Texture modifier

Texture modifiers can be divided into two categories depending on their mode of the operation and rheological characteristics of their solution; thickening agents and gelling agents. Thickening agents are ingredients that are used to increase the viscosity of the continuous phase of the emulsion, whereas gelling agents are ingredients that are used to form a gel in the continuous phase of the emulsion. In O/W emulsion texture modifier uses polysaccharide and the other hand for W/O emulsion used fat crystals (McClements 2005).

The primary function of the thickening agents in food emulsion is to increase the viscosity of the aqueous phase of O/W emulsion. This viscosity enhancement modifies the texture and mouth-feel of food product (thickening). As well as reducing the rate which particle sediment or cream (stabilization). The thickening agent that used is polysaccharide. Their ability to increase viscosity increase the viscosity depends of their molecules weight, degree of branching, conformation and

flexibility (William and Philips 2003; McClements 2005).

Commonly the emulsifiers for the dehydration of the coconut milk emulsion in order to get stability of the powder are casein or skim milk, whereas as the texture modifier use modified starch such as dextrin or maltodextrin (Seow and Gwee 1997; Chiewchan, Phungamngoen et al. 2006; Tangsuphoom and Coupland 2009)

III. 3 Formation of the emulsion

The process of converting two immiscible liquids into an emulsion is known as homogenization, and a mechanical device designed to carry out this process is called a homogenizer (Walstra 1996; McClements 2005). Depending of an emulsion directly from two separate liquids homogenization into two categories; the creation of an emulsion directly from two separate liquids will be defined as primary homogenization, whereas the reduction in size of the droplets in an already existing emulsion will be defined as secondary homogenization (McClements 2005). The physical processes that occur during homogenization usually contain smaller droplets than those that have already undergone primary homogenization such as coconut milk. The emulsion has already stabilized by protein albumin and globulin (Seow and Gwee 1997; Chiewchan, Phungamngoen et al. 2006; Tangsuphoom and Coupland 2008). Thus, homogenization process is occurred in order to get smaller droplet and make stable emulsion.

To form an emulsion that is kinetically stable for a reasonable period of time one must prevent the droplets from merging together after they have been formed (Walstra 1996). This is normally achieved by having a sufficiently high concentration of emulsifier present during homogenization process. The emulsifier absorbs to the surface on the droplet during homogenization forming a protective membrane that prevents the droplets from coming close enough together to coalesce.

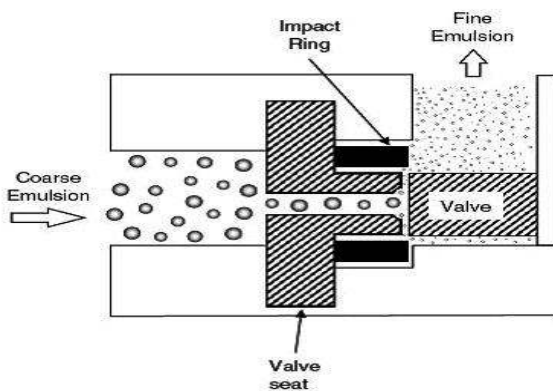


Figure 3 High-pressure valve homogenizers are used to produce emulsions with fine droplet sizes (McClements 2005).

The size of droplets produced during homogenization depends of two ways; first, the initial generation of droplets of small size and, second, the rapid

stabilization of these droplets against coalescence once they formed (McClements 2005; Tangsuphoom and Coupland 2009). Thus, the size of the droplets produced by the homogenizer depends on the balance between two opposing physical process; droplet disruption and droplet coalescence:

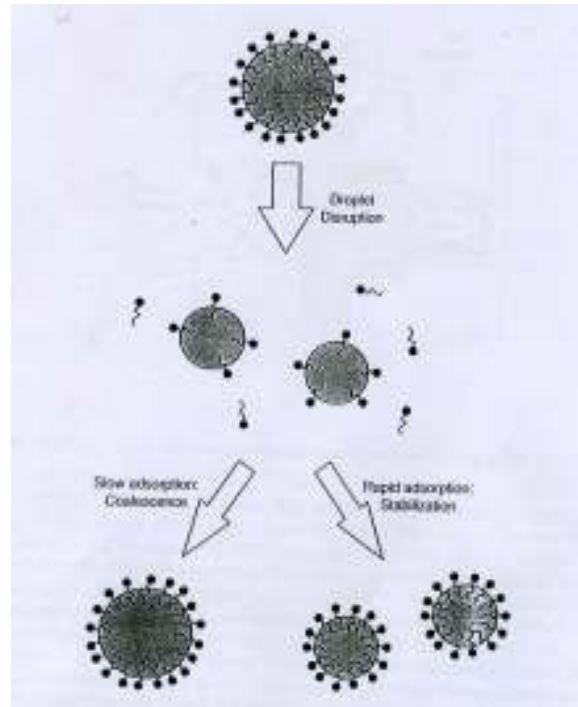


Figure 4. The size of the droplets produced during homogenization depends on the balance between the time for an emulsifier to absorb the surface of oil droplets and the time between droplet – droplet collisions (McClements 2005)

III.4 Droplet disruption

This process involves the disruption of the larger droplets into smaller ones. Whether or not a droplets break up is determined by balance between interfacial force that tend to hold the droplets together and disruptive force generated within homogenization that tend to pull them apart (Walstra 1996; McClements 2005).

An emulsion droplet tends to be spherical because this shape minimizes the thermodynamically unfavorable contact area between the oil and aqueous phase. Changing the shape of the droplet, or breaking it up into a number of smaller droplets, increase this contact area and therefore requires an input of free energy. The interfacial force responsible for keeping a droplet in spherical shape is characterized by *Laplace Pressure* (ΔP_L), which acts across the oil- water interface toward the center of the droplet so that there is a larger

pressure inside the droplet than outside of it

$$\Delta P_L = \frac{4\gamma}{d} \quad (2.1)$$

Here γ is the interfacial tension between oil and water, and d is the droplet diameter. To deform and disrupt a droplet during homogenization it is necessary to apply an external force that is significantly larger than the interfacial force (Walstra 1996; McClements 2005). Thus, it should be possible to produce coconut milk emulsion droplets with smaller sizes of homogenization in present an emulsifier that reduce the interfacial tension (McClements 2005; Tangsuphoom and Coupland 2009).

There are a number also determine the effectiveness of the emulsifiers at reducing the droplet size (Walstra 1996; McClements 2005).

- The rate at which an emulsifier adsorbs to the surface of the droplets during homogenization must be considered immediately after their formation droplets have a low concentration of emulsifier adsorbed to their surface. With the greater amount of the emulsifier accumulated in the surface. Which decreases the interfacial tension and therefore facilitates droplets disruption, thus the quicker the emulsifier adsorbs to the surface of the droplets during homogenization the smaller the droplets produced.

- The ability of the emulsifier to enhance the interfacial rheology of emulsion droplets hampers the break up of droplets, which lead to larger droplet size than those expected from the equilibrium interfacial tension.

III.5 Droplet coalescence

Droplet – droplet collisions are particularly rapid during homogenization because of the intense mechanical agitation of the emulsion. If the droplets are not protected by sufficiently strong interfacial membrane they tend to coalesce with one another during a collision. Immediately after the disruption of an emulsion droplet there is insufficient emulsifier present to completely cover the newly formed surface, and therefore the new droplet are more likely to coalesce with neighbors during a collision. To prevent coalescence it is necessary to form a sufficiently concentration of the emulsifier membrane around the droplets before they have time to collide with the neighbors (Walstra 1996; McClements 2005).

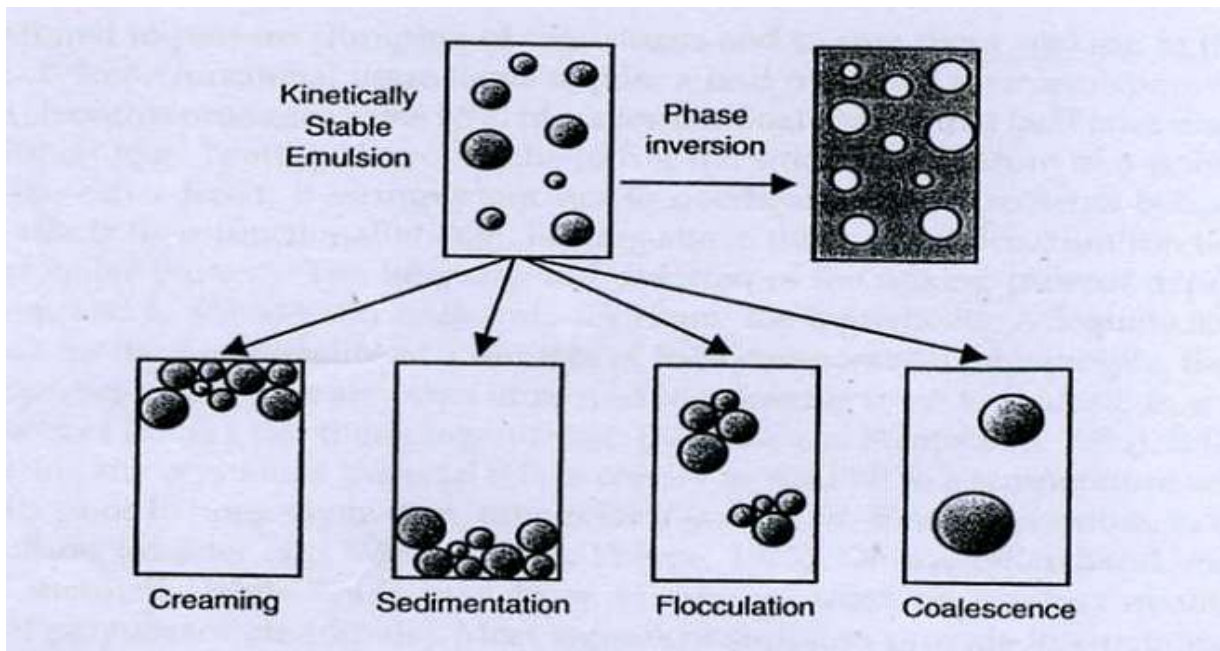


Figure 5 Food emulsion may become unstable through a variety of physical mechanisms including creaming, sedimentation, flocculation, coalescence and phase inversion (McClements 2005).

IV. Stability of emulsion

The term emulsion stability refers to the ability of the emulsion to resist changes in properties over time; the more stable emulsion, the more slowly its properties change. An emulsion may become unstable due to a number of different types of physical and chemical process. Physical instability results in an alteration in the spatial distribution or structural organization of the

molecules, whereas chemical instability results in an alteration in kind of molecule present. The examples of the physical instability are creaming, flocculation, coalescence, partial coalescence, phase inversion and Ostwald ripening (Walstra 1996; McClements 2005; Onsaard, Vittayanont et al. 2005). Whereas oxidation and hydrolysis are common examples of chemical instability (Walstra 1996; McClements 2005).

When we consider about the stability of an emulsion it is important to distinguish between its thermodynamic stability and its kinetic stability (Dickinson and Golding 1997). Thermodynamic tell us whether a given process will occur or not, whereas kinetics tell us the rate at which it proceed if it does occur. The origin of this thermodynamic instability can be illustrated by comparing the free energy system consisting of an oil and aqueous phase before and after emulsification. It can be assumed that the oil and water have similar densities so that no creaming or sedimentation occurred. The importance of kinetic effects can be highlighted by comparing the long term stability of emulsion with the same composition of the same composition but with different droplet size. An emulsion that contains small droplets usually has longer shelf life than one that contains larger droplets, even though it is more thermodynamic unstable (McClements 2005).

In general, the droplets in an emulsion have different density to that of the liquid that surrounds them, and so a net gravitational force acts on them. If the droplets have a lower density than surrounding liquid they have a tendency to move upward, which is referred to as creaming. Conversely, if they have a higher density than the surrounding liquid they tend to move downward, which is referred as sedimentation. Both of creaming and sedimentation are gravitational separation.

The physical basic of gravitational separation is determined by the Stokes' law equation for creaming rate of an isolated spherical particle in a liquid:

$$v_{stokes} = -\frac{2gr^2(\rho_2 - \rho_1)}{9\eta_1} \quad (2.2)$$

The sign of v_{stokes} determines whether the droplet moves upward (+) or downward (-). Where r is the radius of the particle, g is the acceleration due to gravity, ρ is density, η is the shear viscosity, and the subscripts 1 and 2 refer to the continuous phase, respectively (McClements 2005).

Stokes equation assumes that there is no slip at the interface between the droplet and the surrounding fluid, which only strictly true for solid particles. The liquid within the droplet can move when a force is applied to the droplets surface, thus the frictional force that opposes the movement of a droplet is reduced, which causes an increase in the creaming viscosity.

$$v = v_{stokes} \frac{3(\eta_2 + \eta_1)}{3\eta_2 + 2\eta_1} \quad (2.3)$$

The expression reduced to Stokes equation when the viscosity of the droplet is much greater than that of the continuous phase ($\eta_2 \gg \eta_1$). Conversely, when the viscosity of the droplet is much less than that continuous phase (η_1

$\gg \eta_2$). The creaming rate is 1.5 faster than that predicted in Stokes equation (Walstra 1996; McClements 2005). The gravitational separation processes such as flocculation and coalescence.

IV.1 Flocculation

Flocculation is the process whereby two or more droplets associate which each other, but maintain their individual integrities. Droplet flocculation may be either advantageous or detrimental to emulsion quality depending on the nature of the food product. Flocculation accelerates to the rate of the gravitational separation in dilute emulsion, which usually undesirable because it reduces their shelf life (Walstra 1996; McClements 2005).

The presence of the non-adsorbing colloidal particles, such as biopolymer or surfactant micelles, in the continuous phase of an emulsion causes an increase in the attractive force between the droplets due to an osmotic effect associated with the exclusion of colloidal particles from a narrow region surrounding each droplet. This attractive force increases as the concentration of colloidal particles increases, until eventually it may become large enough to overcome the repulsive interaction between the droplets and cause the flocculate. This type of droplet aggregation is usually referred to as depleting flocculation (Walstra 1996; Dickinson and Golding 1997; McClements 2005).

IV.2 Coalescence

Coalescence is the process whereby two or more liquid droplets merge together to forms a single larger droplet. It principal mechanism by which an emulsion move toward its most thermodynamically stable state because it involves a decrease in the contact area between the oil and water phase. Coalescence causes emulsion droplet to cream or sediment more rapidly because of the increase in their size. This process can only occur when droplets are in close proximity and the thin film of material separating them is ruptured. The fact that the droplets must be in close contact means that coalescence is much more dependent on short range forces and the precise molecular details of a system, than either gravitational separation or flocculation (McClements 2005).

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