UNIVERSITI PUTRA MALAYSIA

RHEOLOGICAL BEHAVIOUR OF COCONUT MILK: EFFECTS OF CONCENTRATION AND TEMPERATURE

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By

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To….

My Parents
who gave and nurtured

My Hubby
who shared and inspired

My children
to whom shall I pass

……… *whatever is good in me*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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Chairman: Hussain bin Mohd Salleh, Ph.D.

Faculty : Engineering

The rheological behaviour of coconut milk was studied using a Haake rotational viscometer having a concentric cylinder geometry sensing system. The rheological model of coconut milk, incorporating the effects of concentration and temperature was developed. Experiments were conducted at 4 levels of temperatures in the range of 5°C to 65°C and 6 levels of concentrations ranging from 10% to 50 % total solid (TS). The hysteresis effect was examined by varying the shear rate in an ascending order from $1s^{-1}$ to 1000 s^{-1} followed by a descending order ($1000s^{-1}$ to $1s^{-1}$). The coconut milk, within the ranges of concentration and temperature studied, exhibited different rheological behaviours. Two rheological models, namely the Newtonian and Power Law model were applied to fit the experimental data. The coconut milk with concentrations of lower than 25% TS exhibits Newtonian behaviour. For TS of between 25% to 50%, coconut milk behaves more like a Power Law fluid. Coconut milk that exhibits Newtonian behaviour was of low concentration while coconut milk that follows the Power Law model was of high concentration. The apparent viscosity for low concentration coconut milk showed an exponential type dependence on the concentration while the effect of temperature on the apparent viscosity obeyed the Arrhenius type relationship. The high concentration coconut milk was of a shear thinning fluid with a flow behaviour index, n = 0.567. The flow behaviour index was not significantly affected by the concentration and the temperature in the study. The effect of temperature on the consistency coefficient in Power Law model obeyed the Arrhenius type equation. The effect of concentration on the consistency coefficient obeyed an exponential type equation. The general mathematical models were developed to represent the combined effects of concentration and temperature for low concentration as well as for high concentration coconut milk. Each model developed showed accurate prediction of shear rate. The magnitude of the activation energy, E_a for low concentration coconut milk was 3720.03 cal/mol which was lower than that of high concentration coconut milk (4236.63 cal/mol). An F-test was carried out on the magnitude of shear stress for ascending and descending order shear rates for high concentration coconut milk irrespective of concentration, temperature and shear stress. The test showed that there was no significant difference in the magnitude of shear stress. This indicates that there is no significant effect of time on the rheological behaviour of coconut milk.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian daripada keperluan untuk ijazah Master Sains

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Sifat rheologi bagi santan kelapa telah dijalankan dengan menggunakan viscometer berpusing bersama sistem pengesan silinder sepusat. Model rheologi bagi santan kelapa telah dibangunkan dengan mengambilkira kesan kepekatan dan suhu ujikaji terhadap sifat rheologi santan kelapa. Kajian dijalankan pada 4 tahap suhu pada julat 5-65 °C dan 6 tahap kepekatan pada julat 10-50 % jumlah pepejal keseluruhan (TS). Kadar ricih dijalankan pada aturan menaik ($1s^{-1}$ – $1000s^{-1}$) dan diikuti dengan aturan menurun ($1000s^{-1}$ to $1\ s^{-1}$) untuk mengkaji kesan hysteresis. Santan kelapa pada julat kepekatan yang dikaji menunjukkan sifat rheologi yang berbeza. Dua model rheologi iaitu Newtonian dan Power Law model digunakan untuk disesuaikan dengan data yang diperolehi semasa ujikaji. Santan kelapa yang berkepekatan lebih rendah daripada 25 % TS menujukkan sifat bendalir Newtonian. Manakala, apabila kandungan jumlah pepejal keseluruhan santan kelapa yang melebihi 25% TS, santan kelapa menunjukkan sifat bendalir Power Law. Santan kelapa yang menunjukkan sifat bendalir Newtonian dikategorikan sebagai santan kelapa berkepekatan rendah manakala santan kelapa yang menunjukkan sifat bendalir Power Law dikategorikan sebagai santan kelapa berkepekatan tinggi. Kesan kepekatan terhadap kelikatan ketara bagi santan kelapa berkepekatan rendah mematuhi persamaan berexponen manakala kesan suhu terhadap kelikatan ketara santan kelapa berkepekatan rendah ditentukan menggunakan persamaan Arrhenius. Santan kelapa berkepekatan tinggi adalah bendalir 'shear thinning' dengan indeks sifat aliran, n =0.567. Index sifat aliran tidak dipengaruhi oleh suhu pada julat yang dikaji. Kesan suhu tehadap pekali konsisten di dalam model Power Law mematuhi persamaan Arrhenius manakala kesan kepekatan pula mematuhi persamaan berexponen. Model matematik dibentuk untuk menunjukkan kombinasi kesan suhu, kepekatan dan kadar ricih tehadap kelikatan ketara setiap satu untuk santan kelapa berkepekatan rendah dan santan kelapa berkepekatan tinggi. Nilai tenaga pengaktifan bagi santan kelapa berkepekatan rendah adalah 3720.03 kal/mol yang mana lebih rendah daripada tenaga pengaktifan bagi santan kelapa berkepekatan tinggi (4236.63 kal/mol). Analisa statistik (F-test) yang dijalankan pada nilai tekanan ricihan bagi kadar ricih aturan menaik dan menurun bagi santan kelapa berkepekatan tinggi tanpa mengambilkira kepekatan, suhu dan kadar ricih. Analisa yang dijalankan menunjukkan tiada perbezaan yang ketara bagi nilai tekanan ricihan bagi kedua-dua aturan. Ini menjelaskan bahawa kesan masa terhadap sifat rheologi santan kelapa adalah kecil dan tidak diambilkira.

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Knowledge is a real blessing and reward to those who continually seek it.

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the partial requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NORAZIAH MUDA @ OMAR
Date:

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GLOSSARY OF TERMS

Roman Letters

A	Shear rate at the beginning of shearing of equation 2.3, Pa
a	Constant in equation 4.1
a_k	Constant in equation 4.6
APPC	Asia and Pacific Coconut Community
Asc	Ascending order shear rate
B	Rate of structural breakdown of equation 2.3, s^{-1}
b	Constant in equation 4.1
b_k	Constant in equation 4.6
C	Concentration
Des	Descending order shear rate curve
dv/dy	Velocity gradient, s-1
e,f,g and h	Model parameter for equation 2.13
E_a	Activation energy, Cal/mol
F	Force, kg/m^2
F_o	Process time at 121.1 °C (250° F), min
Ha	Hectare
K	Consistency coefficient in Power law model, ($Pa.s^n$)
k_1	Rate constant
N	Flow behaviour index in Power law mode
Pa	Pascal
psi	Pound per square inch
R	Universal Gas constant (cal mol^{-1} K^{-1})
R^2	Coefficient of determination (dimensionless)
s	Second
T	Absolute temperature (Kelvin)
t	Time (sec.)
TS	Total solid

Ts_f	Final total solid content, %
Ts_i	Initial total solid content, %
v	Velocity, m/s
W_b	Weight of sample before drying, g
W_d	Weight of sample after drying, g
W_i	Initial weight, g
y	Distances between two plates, m

Greek letters

α	Constant
τ	Shear stress, Pa
τ_o	Yield stress, Pa
λ	Time dependent structural parameter
λ_e	Equilibrium time dependent structural parameter
η	Viscosity, Pa s
η_a	Apparent viscosity, Pa s
η_o	References viscosity, Pa s
$\dot{\gamma}$	Shear rate, s^{-1}
β	Constant
μ	Dynamic viscosity, Pa s

CHAPTER 1

INTRODUCTION

Coconut milk is becoming an increasingly important raw material in home cooking as well as in the food processing industries. It is extracted from the solid coconut endosperm. It is estimated that 25% of the world coconut output is consumed as coconut milk (Gwee, 1988). Coconut milk is a major and an essential ingredient in the preparation of a wide variety of food products such as curry, desserts, coconut jam spread, coconut syrup, coconut cheese, bakery products, beverages and coconut tofu (Gonzales, 1986; Gwee, 1988). When combined with skim milk (cow's milk), a new product with a good commercial potential is developed (Seow and Gwee, 1997). It can also be used as a substitute for milk in some desserts. Chocolate and other confectionaries are exotically flavoured with coconut milk.

In commercial production, coconut milk is extracted by pressing grated coconut endosperm using the hydraulic or the screw press (Cancel, 1979). The milk is then filtered through a cloth filter or centrifuged at low speeds to remove finely comminute particles of coconut pulp without breaking the emulsion. The result is a milky white, opaque emulsion with a sweet coconut flavour.

Untreated coconut milk spoils rapidly even under chilled storage. It is a very rich medium which can support the growth of the common spoilage microorganisms (Seow and Gwee, 1997). Over the years, many attempts have been made to commercially extend the shelf life of coconut milk through canning, aseptic packaging and spray drying. The manufacturing processes of canned and aseptic packaging of coconut milk involves heat treatment for sterilization and pasteurisation and under continuous flow in the pipeline. The coconut milk is pumped and sheared prior to being filled into the container. The mechanical handling of coconut milk involves both the deformation and the flow of a material and these mechanical properties are referred to as rheological properties.

Rheology is defined as a science of flow and deformation of matter and describes the interrelationships between force, deformation and time (Rao, 1999). The term comes from the Greek words *rheos* meaning to flow. Normally, deformation pertains to solid, and flow to liquid. Despite the fact that the rheology of fluid and semisolid food had established a growing interest during the last few years, there is a need to appreciate the basic principals of rheological behaviour and proper measurement of rheological properties as well as the influence of composition and structure on those properties.

Rheological properties of food material in processing are important in the design of flow processes, quality control, storage, processing stability of measurement and predicting texture (Davis, 1973). Rheological data is essential in optimising equipment design, ensuring adequate heat treatment and limiting overheating of product in food exposed to thermal processing conditions (Anderson *et al.*, 1999), evaluating heating rates during such engineering operation as in aseptic processing (Rao, 1999), as well as to estimate velocity, shear and residence time distribution in extrusion and continuous mixing (Kokini, 1992).

The knowledge of rheological properties is also important in the development phase of a new product, relating the properties with sensory towards understanding consumer perceptions of food texture, provide important measurement to facilitate process design and development and in selecting on line measurement technique (Borwankar, 1992).

Food, in general cannot be categorised as simply solid or liquid. They are usually classified as solids, gels, homogeneous liquids, suspension of solids in liquids and emulsions. Fluid foods are those that do not retain their shape but take the shape of their containers. Fluid foods that contain significant amounts of compounds and suspended solids exhibit non-Newtonian behaviours. Many non-Newtonian behaviour are characterized by both viscous and elastic properties called visco-elastic behaviour. Since fluids and semisolid foods exhibit a wide variety of rheological behaviours ranging from Newtonian to time dependent, dilatants, thixotropy etc (Rao, 1999), the understandings of these rheological behaviours are of considerable importance.

Dynamic rheological testing is used to characterize visco-elastic properties of foodstuffs. It involves subjecting the test sample to a cyclic loading in where the stress and the strain vary harmonically with time. Dynamic testing is a non-destructive technique for investigating the structure of foods. Using this technique, several useful rheological parameters can be obtained which quantify the visco-elastic characteristics of the material.

Studies on the rheological characteristics of coconut milk have not been explored widely. Despite the fact that coconut milk is an indispensable ingredient in many of the traditional cuisines especially of South East Asian countries, information on its rheological behaviour is very important. The rheological data over the range of temperature would provide insight into rheological characteristic of the coconut milk, which is essential for pumping system and equipment design and analysis of various processes. The rheological data on coconut milk at different concentrations are also essential because varying the coconut milk concentration often lead to dramatic changes in their viscoelastic behaviour. The applications of the coconut milk are also varied depending on their concentrations, for instance, thick coconut milk normally use for making dessert while thin coconut milk is use for light curries or puddings.

The rheological data of coconut milk at different concentrations and temperatures are essential in the design of pumping systems, the analysis of various processes, the design of equipments and machineries, the formulation of new products and the control of quality. This study intends to contribute useful data to the field of rheology, particularly those relating to coconut milk. The objectives of this study are:

1) to study the effect of temperature and concentration on the rheological behaviour of coconut milk;
2) to develop a rheological model for coconut milk as a function of concentration and temperature;
3) to study the effect of time on the rheological behaviour of coconut milk by examining the hysteresis effect.

CHAPTER 2

LITERATURE REVIEW

The science of food rheology had advanced considerably during the past few decades. Numerous rheological studies on various foodstuffs can be found in the literature. The basic concept of rheology, various mathematical models, rheological instrument and measurement technique and factors that influence the rheological properties of food product has been reviewed and discussed in the following sections. In addition, general information on coconut milk and its product is also presented. Finally major studies on the rheological properties of different fluid and semisolid food is reviewed.

2.1 Coconut Milk

Coconut milk is a generic term for the aqueous extract from solid endosperm of coconut *(Cocos nucifera)*. Although oil recovery is the major concern in the coconut industry, there appears to be increasing demand for the coconut milk extract for use in home and in the food industries. In Malaysia, as per information from Asia and Pacific Coconut Community (APPC), the total coconut plantation in Malaysia in 2000 was 230000 Ha. (Ministry of Primary Industry, 2001). Those cultivated coconuts were exported in the form of fresh coconut, copra, coconut oil, desiccated coconut, coconut milk, and other coconut by-product. About 0.8 % of the total export earning, which is equivalent to 2181 million tones per annum, was exported in the form of coconut milk. It has also been