UNIVERSITI PUTRA MALAYSIA

# RHEOLOGY OF POMELO JUICE

SAMANEH KESHANI

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**SAMANEH KESHANI**

**MASTER OF SCIENCE**
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# RHEOLOGY OF POMELO JUICE

**By**

**SAMANEH KESHANI**

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**RHEOLOGY OF POMELO JUICE**

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**SAMANEH KESHANI**

**April 2009**

**Chairman: Luqman Chuah Abdullah, PhD**

**Faculty: Engineering**

The proximate analysis studies on pomelo juice provide useful data for its juice processing industry. The studies on the physico-chemical properties such as water activity, pH and density make better prediction of its behavior at the relevant processing concentration and temperature. The Pomelo juice is found to have high moisture content which contributes to high water activity and specific heat of capacity. Also, the PH of pomelo juice obtained indicates that pomelo juice is acidic fluid. The predictions of density yielded high regression coefficient. In general, the density increases with increasing concentration but decreases with temperature increase. The density of pomelo juice also presented a stronger dependence on concentration than the temperature.

Rheology is the science of deformation and flow behavior of fluid. Knowledge of rheological properties of fluid and their variation with temperature and concentration have been globally important for industrialization of food technology for quality, understanding the texture, process engineering application, correlation with

sensory evaluation, designing of transport system , equipment design (heat exchanger and evaporator), deciding pump capacity and power requirement for mixing.

The aim of this study was to determine the rheological behavior of pomelo juice at different concentrations (20-60.4 °Brix) and temperatures (23-60°C) by using a rotational Haake Rheostress 600 rheometer and a cone and plate geometry sensor (35mm diameter, 2° cone angle), with a gap distance of 0.105 mm. Shear rates employed ranged from 0-1000 $s^{-1}$.

Pomelo juice was found to exhibit both Newtonian and Non-Newtonian behavior. For lower concentration the Newtonian behavior is observed while at higher concentration Non-Newtonian behavior was observed. Standard error (SE) method was selected on the basis to carry out the error analysis due to the best fit model. For the four models the values of SE show that the Herschel-Bulkley and Power Law models perform better than the Bingham and Casson models but Herschel-Bulkley model is true at higher concentration.

The experimental data of apparent viscosity versus shear rate were successfully described by the Power-law model. The model parameters; flow behavior index, n varied in the range of 0.65-0.89, whereas the values for the consistency coefficient, K, were in the range of 0.004-0.3 (Pa.$s^n$). Apparent viscosity and consistency coefficient of pomelo juice increased with increasing concentration and decreasing temperature. The effect of temperature on n was found to be significant but did not follow any descriptive trend.

The effect of temperature on pomelo juice is best described by the applicability of the Arrhenius model related to apparent viscosity, $\eta$ at a constant shear rate of $100s^{-1}$ or the consistency index of the power law model. Activation energies ($E_a$) of the pomelo juice appeared in the range of 9103.83-23391.43 J/mol as the pomelo juice concentration was increased from 20 to 60.4$^{\circ}$Brix.

The relationship between $\eta$ or K of pomelo juice concentration was explained by exponential and power functions while pomelo juice observed that at higher concentration will have higher viscosity.

The master-curve was investigated for comparing data from different products at a reference temperature of 40$^{\circ}C$. Multiple regression analysis indicated Master-Curve presents good agreement for pomelo juice at all concentrations studied with $R^2$ >0.8.

Response surface methodology (RSM) was applied to investigate the effects of the three main independent parameters; rotation, temperature and time on the pomelo juice concentration and optimizing the operating conditions of the treatment process. Values of parameters required to obtain efficiency of concentration pomelo juice are suggested based on rotation speed (60-120 rpm), temperature (40-60$^{\circ}C$) and time (5-60 min).

It is clear from the result that the concentration increased when the temperature,

rotation speed and time increased. It can be inferred that any parameters, individually, had positive effect on increase of concentration. The main effects of parameters are in following order: Main effect of time> temperature> rotation speed.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagi memenuhi keperluan untuk ijazah Master Sains.

**SIFAT REOLOGI JUS LIMAU BALI PEKAT**

Oleh

**SAMANEH KESHANI**

**April 2009**

**Pengerusi : Luqman Chuah Abdullah, PhD**

**Fakulti: Kejuruteraan**

Kajian analisis anggaran terhadap jus limau tamun menyediakan data berguna kepada industri pemprosesan jus sementara itu kajian terhadap sifat fizikokimia seperti kegiatan air, pH, dan ketumpatan membolehkan ramalan bagi tingkah laku nya pada kepekatan dan suhu prosess relevan. Jus limau tamun didapati mempunyai tinggi kandungan lembapan yang menyumbang kepada kegiatan air tinggi dan haba spesifik keupayaan. Selain itu, pH jus limau tamun didapati menunjukkan yang jus limau tamun adalah bendalir berasid. Ramalan-ramalan bagi ketumpatan menghasilkan pekali regresi yang tinggi. Secara umum, ketumpatan meningkat dengan bertambahnya kepekatan tetapi berkurangan dengan peningkatan suhu. Ketumpatan jus limau tamun juga menunjukkan pergantungan keatas kepekatan dibandingkan dengan suhu.

Reologi adalah sains penyahbentukan dan prestasi aliran bendalir. Pengetahuan sifat-sifat reologi tentang makanan bendalir dan variasi mereka dengan suhu dan kepekatan adalah penting secara global untuk pengindustrian teknologi makanan untuk kualiti, pemahaman tekstur, pemohonan kejuruteraan proses, pembetulan dengan penilaian deria, penciptaan

sistem pengangkutan, reka bentuk alatan (penukar haba dan penyejat), penentuan kapasiti pam dan keperluan kuasa untuk pencampuran.

Tujuan kajian ini adalah untuk menentukan sifat-sifat reologi jus limau tamun pada kepekatan (20-60.4%) dan suhu (23-60°C) yang berlainan dengan menggunakan berputar Haake Rheostress 600 reometer dan sebuah kon dan pengesan plat geometri (35mm garis pusat, 2° sudut kon), dengan jarak jurang 0.105 mm. Kadar-kadar ricih digunakan dalam 0-1000 s-1.

Jus pomelo didapati memperlihatkan kedua-dua ciri Newtonian dan Bukan-Newtonian. Pada kepekatan yang rendah, jus memperlihatkan ciri Newtonian manakala pada kepekatan yang lebih tinggi ciri Bukan-Newtonian dapat dilihat. Kaedah Ralat Piawai (SE) telah dipilih sebagai asas untuk menganalisa ralat, berdasarkan kepada model yang paling sesuai. Bagi keempat-empat model tersebut, didapati nilai ralat piawai model Herschel-Buckley dan model Hukum Kuasa memberikan keputusan yang lebih baik berbanding model Bingham Dan Casson, walaubagaimanapun pada kepekatan lebih tinggi ciri-ciri model Herschel-Buckley diperhatikan.

Data experimen kelikatan ketara lawan kadar ricihan telah berjaya diterangkan oleh model Power Law. Parameter model; indek sifat-sifat aliran, n berubah dalam julat 0.65-0.89, manakala nilai-nilai untuk pekali kekonsistenan, K, berada dalam julat 0.004-0.3 (Pa.sn). Kelikatan ketara dan pekali kekonsistenan jus limau tamun meningkat dengan bertambah ketumpatan dan pengurangan suhu. Kesan suhu pada n didapati adalah penting tetapi tidak mengikut mana-mana pola yang boleh diterang.

Kesan suhu pada jus limau tamun adalah terbaik digambarkan dengan kebolehgunaan model Arrhenius berkaitan dengan kelikatan ketara, pada kadar ricih malar 100s atau indek kekonsistenan model Power Law. Tenaga-tenaga pengaktifan ($E_a$) jus limau tamun muncul dalam julat 9103.83-23391.43 J/mol dengan ketumpatan jus limau tamun meningkat dari 20 hingga 60.4 Brix.

Hubungan antara $\eta$ atau K kepekatan jus limau tamun telah dijelaskan dengan eksponen dan kuasa fungsi sementara jus limau tamun diperhatikan yang pada ketumpatan lebih tinggi akan mendapat kelikatan yang lebih tinggi.

Induk lengkung telah disiasat untuk membandingkan data dari produk berbeza pada suhu rujukan 40°C. Analisis regresi berbilang menunjukkan Master-Curve membentangkan perjanjian baik untuk jus limau tamun dalam semua kajian kepekatan dengan $R^2$ >0.8.

Response surface methodology (RSM) diaplikasikan untuk menyiasat kesan tiga parameter mendiri yang utama; putaran, suhu dan masa terhadap kepekatan jus limau tamun dan mengoptimakan syarat-syarat beroperasi proses rawatan. Nilai parameter yang diperlukan untuk mendapat kepekatan jus pomelo yang lebih effisen adalah berdasarkan kelajuan putaran (60-120 rpm), suhu (40-50 $^\circ C$ ) dan masa (5-60 min).

Ia adalah jelas daripada hasil bahawa kepekatan bertambah apabila suhu, kelajuan putaran dan masa bertambah. Ia boleh disimpulkan bahawa mana-mana parameter, secara individu, mempunyai kesan positif kepada peningkatan kepekatan. Kesan-kesan utama parameter adalah dalam aturan berikut: Kesan utama masa> Suhu> kelajuan putaran.

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I certify that an Examination Committee met on 29 April 2009 to conduct the final examination of Samaneh Keshani on her Master of Science thesis entitled "Rheological behavior of Pomelo Juice Concentrates" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree.

Members of the Examination Committee are as follows:

**Thomas Choong Shean Yaw, PhD**
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

**Robiah Yunus, PhD**
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

**Siti Mazlina, PhD**
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

**Ir.Hj.Wan Ramli, PhD**
Professor
Faculty of Engineering
Universiti Kebangsan Malaysia
(External Examiner)

**BUJANG KIM HUAT, PhD**
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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

**Luqman Chuah Abdullah, PhD**
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

**Jamilah Bakar, PhD**
Professor
Faculty of Food Science &Technology
Universiti Putra Malaysia
(Member)

**Russly Abdul Rahman , PhD**
Professor
Faculty of Food Science &Technology
Universiti Putra Malaysia
(Member)

______________________
**HASANAH MOHD GHAZALI, PhD**
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9 July 2009

## 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.

**SAMANEH KESHANI**

Date: 22 June 2009

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## LIST OF NOTATIONS / SYMBOLS

**Notations / symbols**

| | | |
|---|---|---|
| $\tau_{\circ}$ | Shear stress | Pa |
| $\kappa'$ | Bingham Plastic viscosity | |
| $\eta$ | Apparent viscosity | Ns/m$^2$, pa s |
| k | Consistency index | Ns$^n$/m$^2$ |
| $\dot{\gamma}$ | Shear rate | 1/s |
| n | Flow behavior index | |
| K | Consistency coefficient-(power-low, Herschel-Bulkley, Arrhenius-type) | Pa. $s^n$ |
| n | Flow behavior index-(power-low) | |
| $\tau$ | Shear stress (Newton's law when the flow is laminar) | Pa |
| $\mu$ | Newtonian viscosity | |
| $\gamma$ | Shear rate (Newton's law when the flow is laminar) | 1/s |
| $\eta_{\circ}$ | Experimental Constants (Arrhenius-type equation) at constant shear rate $100\,s^{-1}$ | |
| Ea | Activation energy | J/mol |
| R | Universal gas law constant, Arrhenius-type equation | 8.314 J/g.mol.K |
| T | Absolute temperature (Arrhenius-type equation | ºK |
| $\tau^{0.5}$ | Shear Stress (Casson model) | Pa$^{0.5}$ |
| RO | Reverse osmosis | |
| $\tau_{\circ c}^{0.5}$ | Casson yield | Pa$^{0.5}$ |
| $k_c$ | Casson constant | Pa s$^{0.5}$ |
| $\eta_{ca}$ | Casson plastic viscosity | |
| k$_{\circ}$ | Experimental constants (Arrhenius-type equation) | |
| $A'$ | Frequency factor at constant shear rate $100\,s^{-1}$ | |
| $B$ | Constant for equation (2.12) | |
| $B'$ | Constant for equation (2.13) | |

| | | |
|---|---|---|
| C | Concentration | °Brix |
| $a_w$ | Water Activity | Dimensionless |
| $a_T$ | Shift factor | Dimensionless |
| $\rho$ | Density | $Kg/m^3$ |
| $m_c$ | Mass fraction of carbohydrate | |
| $m_p$ | Mass fraction of protein | |
| $m_f$ | Mass fraction of fat | |
| $m_a$ | Mass fraction of ash | |
| $m_m$ | Mass fraction of moisture | |
| $C_P$ | Specific heat | KJ/Kg.°C |
| F | Force | N |
| A | Area | $m^2$ |
| υ | Velocity of moving fluid | m/s |

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