UNIVERSITI PUTRA MALAYSIA

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To…

My Mother and Father

Who gave and nurtured

……whatever is good in me

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

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Chairman: Ibrahim Omar Mohamed, Ph.D

Faculty : Engineering

Concentration is one of the important operations in food industry with applications ranging from the production of condensed milk, paste and purees from fruits. Using an agitated thin film evaporator allows for the concentration to be undertaken at low temperature and short residence time with reduced heat loss for heat sensitive material.

The parameters that influence an agitated thin film evaporator process are steam temperature; product feed rate, vacuum pressure, rotor speed, physical and thermal properties of the product and the overall heat transfer coefficient. These indicate that the process is a very complex heat and mass transfer an operation that requires optimization in order to reduce the cost and maintain the product quality

The overall heat transfer coefficients (U_i) of pineapple juices (fresh juice of 11.3, 14.4, 19.9, and 27.3 °Brix) were determined using a laboratory scale agitated thin film evaporator (ATFE) under different rotational speeds (200, 400, and 600 rpm),

liquid flow rates (25, 35, and 45 l/h), and at constant steam and vacuum pressure. The Experiments were conducted with water and (U_i) for water determined under the different parameters.

Some equations to predict the Thermophysical properties of the pineapple juices at different concentrations were derived from the experimental data (density and viscosity) and others taken from the literature.

The overall heat transfer coefficients (U_i) were determined based on inner heat surface area. The magnitude of (U_i) ranged from 390 to 2700 W/m^2°C. The performance of the evaporator was evaluated and determined .Some of the pineapple juices quality parameters before and after concentration were studied for effects of concentration by ATFE .The juice color was very little changed based on the Hunter lab values measurements, while the vitamin C contents were decreased by 10.1%, and 23.13% for the 16.8 and 40.3 °Brix ,respectively

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

PENILAIAN KECEKAPAN PENGGUNAAN PENYEJAT FILEM NIPIS TERGONCANG KE ATAS KEPEKATAN JUS BUAH NENAS

Oleh

IBRAHIM GREIBY EMHAMED

Mei 2004

Pengerusi : Ibrahim Omar Mohamed ,Ph.D
Fakulti : Kejuruteraan

Tahap kepekatan merupakan aspek operasi yang penting di dalam industri pemakanan. Penggunaannya merangkumi proses penghasilan susu pekat, pes dan puree dari buah – buahan. Penggunaan penyejat filem nipis tergoncang membolehkan kepekatan diambil pada suhu rendah dan tempoh penyimpanan yang lebih pendek. Ini akan mengakibatkan pengurangan kehilangan haba untuk bahan – bahan sensitif kepada haba.

Parameter – parameter yang mempengaruhi proses penyejat filem nipis tergoncang adalah – adalah suhu stim, kadar kemasukan produk, tekanan vakum, kadar rotor, ciri –ciri fizikal dan termal produk serta pekali pemindahan keseluruhan haba. Ini menunjukkan bahawa proses ini adalah proses pemindahan haba dan jisim yang kompleks dan memerlukan penggunaan paling optima untuk mengurangkan kos serta memlihara kualiti produk.

Pekali pemindahan haba secara keseluruhan (Ui) jus nenas (Jus segar 11.3, 14.4, 19.9 dan 27.3 °Brix) ditentukan dengan menggunakan skala makmal penyejat filem nipis tergoncang dibawah pelbagai kelajuan pemutaran (200, 400 dan 600 rpm), kadar pengaliran cecair (25, 35 dan 45 l/h) serta tekanan stim dan vakum yang konstan. Eksperimen – eksperimen ini dijalankan dengan menggunakan air dan (Ui) untuk air ditentukan di bawah parameter – parameter yang berbeza.

Beberapa persamaan untuk meramalkan ciri – ciri termo–fizikal jus nenas pada tahap kepekatan berlainan diterbitkan daripada data eksperimen (kepekatan dan kelikatan) dan yang lainnya diambil daripada sorotan kajian.

Pekali pemindahan haba keseluruhan (Ui) ditentukan berasas kepada keluasan kawasan haba dalaman. Julat magnitud (Ui) adalah dari 390 ke 2700 W/m^2 °C. Kecekapan penyejat dinilai dan ditentukan beberapa parameter kualiti jus nenas sebelum dan selepas kepekatan dikaji untuk melihat kesan kepekatan oleh penyejat filem nipis tergoncang. Keputusannya ialah tidak terdapat perbezaan yang banyak ke atas warna jus berdasarkan pengukuran nilai makmal Hunter, ,manakala kandungan vitamin C berkurangan 10.1% untuk 16.8 °Brix dan 23.13% untuk 40.3 °Brix.

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Ibrahim Greiby Emhamed
Universiti Putra Malaysia.
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NOMENCLATURE

Roman Letters

.a	Degree of greenness/redness color
A	the area of the heat exchanger (m^2)
A_i	heat transfer area based on inside tube diameter (m)
A_o	heat transfer area based on out side tube diameter (m)
A_m	log mean heat transfer area (m^2)
b	Degree of blueness/yellowness color
B	Number of blades on the shaft
C	Color Chroma or saturation
Cp	specific heat of sample, kJ/kg°K
D	diameter of agitator (m)
De	equivalent diameter for non-round cross section (m)
g	gravitational acceleration(m\s^2)
k	thermal conductivity (W/m°C)
E_a	activation energy for flow, J/mol·kg
h°	Color hue angle (°)
h_f	enthalpy of dilute liquid feed (kJ/kg)
h_p	enthalpy of concentrated product (kJ/kg)
$H_s(T_s)$	enthalpy of saturated vapor at temperature T_s (kJ/kg)
$H_v(T_b)$	enthalpy of saturated vapor at temperature T_b(kJ/kg)
$h_s(T_s)$	enthalpy of condensate T_s(kJ/kg)
L	Color lightness(for color measurements)
L	length of the evaporator (m)
m_f	the mass flow rate of dilute liquid feed (kg/s)
m_v	the mass flow rate of vapor (kg/s)
m_p	the mass flow rate of concentrated products (kg/s)
m_s	the mass flow rate of steam (kg/s)
N	agitator speed, revolutions/hr
n_B	number of blades on agitator
R	gas constant, 8.13 J/K·mol·kg in Equations 4.4 and 4.7
R	radius of the tube in Equation 4.6 (m)
q	the rate of heat transfer (W)

Q	Volumetric flow rate (L/s)
r	the Correlation coefficient
r^2	the coefficient of determination
T_b	boiling temperature maintained inside the evaporator chamber (°C).
T_f	the temperature of juice feed (°C)
T_m	The arithmetic means temperature of the fluid(°K)
T_s	temperature of stream (°C)
TCD	Total color difference
U	the overall heat transfer coefficient ($W/m^2°C$)
v	axial flow velocity, m/hr
x_f	the solid fraction in feed stream
x_p	the solid fraction in product stream

Dimensionless Groups:

De	$5.492\left(\frac{mf\,\mu}{\rho^2 gB}\right)^{0.25}$	The equivalent diameter
Fr	N^2D^2/μ	Froude number
FrD_{De}	N^2DeD/μ	Froude number for equivalent diameter
Gr	$L^3.g.\rho^2.\beta.(T_w\text{-}Ta)/\mu^2$	Grashof number
Nu	$h_p D/k$	Nusselt number
Nu_e	$h_p De/k$	Nu (characteristic dimension equivalent diameter
Pr	$\mu C_p/k$.	Prandtl number
Re_r	$ND^2\,\rho/\mu$	rotational Reynolds number
Re_e	$8m_f\backslash\mu De.B$	Reynolds number for equivalent diameter
Re	$v\,D\,r/\mu$	Axial flow Reynolds number
Re_f	$m_f/\pi D\mu$	Film Reynolds number
ΔT_{lm}	$\left(\frac{(T_s - T_b) - (T_s - T_f)}{\ln\frac{(T_s - T_b)}{(T_s - T_f)}}\right)$	Log Mean Temperature Deference

Greek Letters

μ_{app}	apparent viscosity (Pa·s)
μ_f	Viscosity at feed temperature (Pa·s)
μ_b	Viscosity at evaporation temperature(Pa·s)

ρ	density (kg/m^3)
τ	Shear stress (Pa)
γ	Shear rate (1/s)
β	Constant (1/°K)

CHAPTER 1

INTRODUCTION

1.1 Overview

In evaporation, heat is applied to a solution to vaporize the solvent, which is usually water. The heat is generally derived from the condensation of a vapor, such as steam, on one side of a metal surface with the liquid to be evaporated on the other side. The equipment used depends primarily on the configuration of the heat-transfer surface and the means of agitating the liquid. In an evaporator, the main resistance to heat transfer is the liquid film itself. One way to improve heat transfer is to increase turbulence in this film by agitation. This is done in a modified falling-film evaporator with only a single large jacketed tube containing an internal agitator. Liquid enters at the top of the tube and as it flows downward, is dispersed into a turbulent film by agitator blades. The concentrated solution leaves at the bottom and the vapor through a separator at the top. This type of evaporator is very useful for highly viscous materials, and used for heat-sensitive liquids such as rubber latex, gelatin and fruit juices. However, it has a high cost with only a small capacity (Geankoplis, 1993).

Thin film mechanical evaporators are extensively used in the food and chemical industries for concentrating high viscosity or heat-sensitive products. Their major advantage is their mechanical rotary close clearance blades which considerably improve the product side heat transfer. Vigorously agitated liquid films are continuously sprayed and scraped off the heat transfer wall by the blades minimizing the product degradation by the very short heat contact time.

Parker (1965) reported that the overall heat transfer coefficient for a thin film scarped surface evaporator (TFSSE) varied between 1134 and 1985 W/m^2.°C. He also explained the factors controlling the residence time for specific applications and stated that apart from the major factors, such as the length-to-diameter ratio and rotor speed, the feed rate can provide some degree of control.

Evaporative concentration of fluid foods presents major drawbacks. Firstly, is the heat-degradation of the sensory (color, taste and aroma) and nutritional (vitamins, etc.) values of the finished concentrated product. It is well known that in the first few minutes of evaporative concentration, most of the aroma compounds in the raw juices are lost and the aroma profile undergoes an irreversible change.

The transfer of heat to or from viscous or heat-sensitive liquids is a problem process confronting engineers in several industries, especially the food industry. Manufacturers of food processing equipment have to consider liquid products, such as fruit juice and milk, which viscosities are little more than that of water, to very viscous products, such as fruit concentrates, purees, pie fillings and puddings (Abichandani, 1987)

Skoczylas (1967) described the construction and operating characteristics of several film evaporators. He considered the effects of pressure, temperature, feed rate and the usually applied heat loads on their performance. With respect to spreading the liquid over the heating surface, film evaporators can be divided into two groups -

static (liquid flow under gravity, like the falling-film evaporator) and mechanical (liquid flow by special carbon brushes, like the mechanical-film evaporator).

Agitation of a product film during heating prevents scaling and produces a highly uniform concentrate. Agitated thin-film evaporators have been added to the existing lines of concentration equipment as high-density "finishers" for flexibility (Fischer, 1965).

The food industry today is very rapidly developing. There are many parameters of importance to the industry. The therrmophysical properties, such as density and viscosity, are continuously monitored in the clarified fruit juice industry. The thermophysical information required can be obtained experimentally, but this is not always convenient. Such experiments can take a long time and are expensive. The convenient way is to use established models to derive the information from the data available.

1.2 Objectives Of this study:

This project was undertaken to:

- Determine the overall heat transfer coefficient (U) of an agitated thin-film evaporator at different flow rates ,rotor speeds and concentrations at constant steam and vacuum pressure using pineapple juice as the feed material.
- Evaluate the performance of the agitated thin-film evaporator for the concentration of pineapple juice.
- Monitor the quality degradation of the juice during concentration.