PARAMETER STUDY ON LOW TEMPERATURE VACUUM DRYING WITH INDUCED NUCLEATION BOILING FOR DEWATERING STINGLESS BEES HONEY

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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STUDENT'S DECLARATION

I hereby declare that the work in this 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 Universiti Malaysia Pahang Al-Sultan Abdullah or any other institutions.

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ABSTRAK

Salah satu isu yang dihadapi oleh penternak lebah kelulut adalah berkaitan penyimpanan madu lebah kelulut (SBH) pada suhu bilik. Ini kerana SBH mengandungi kandungan air yang tinggi yang boleh menyebabkan penapaian. Oleh itu, proses penyahairan adalah perlu untuk mengurangkan kandungan air dan mengelakkan penapaian. Kaedah konvensional yang digunakan untuk menurunkan kandungan air madu adalah tidak cekap dan berpotensi merosakkan kandungan khasiat madu. Oleh itu, kaedah Pengeringan Vakum Suhu Rendah dengan Pendidihan Nukleasi Teraruh (LTVD-NB) telah dicipta untuk menyelesaikan masalah kecekapan penyahairan madu di samping mengekalkan kualiti madu. Oleh kerana kaedah LTVD-NB melibatkan pendidihan nukleat, oleh itu kekasaran permukaan (SR) dan suhu penyahairan boleh menjejaskan prestasi penyahairan madu. Walau bagaimanapun, kajian tentang kesan SR dan suhu penyahairan terhadap pendidihan nukleat adalah terhad. Adalah diketahui bahawa SR menentukan rongga dan mempengaruhi proses pemindahan haba mendidih, manakala suhu menentukan fluks haba (*q”*). Adalah dipercayai bahawa proses pemindahan haba mendidih berkait secara langsung dengan nukleat gelembung pada permukaan yang dipanaskan. Walau bagaimanapun, terdapat jumlah penyelidikan yang terhad mengenai kesan SR dan suhu penyahairan terhadap ciri-ciri nukleasi gelembung dalam madu. Oleh itu, objektif kajian ini adalah untuk menyiasat kesan suhu dan SR paip pemanas keluli tahan karat ke atas kadar penyahairan, pemindahan haba mendidih nukleat (NBHT), dan ciri gelembung nukleat semasa penyahairan SBH. 200 g sampel SBH dipanaskan selama lima minit pada tiga suhu berbeza, iaitu 40, 45, dan 50 °C menggunakan paip pemanas keluli tahan karat dengan SR 0.80, 3.39, 8.82, dan 11.33 µm pada tekanan 5 kPa. Kamera digital digunakan untuk menangkap dan merekod pembentukan nukleat gelembung pada permukaan pemanas semasa eksperimen. Pembentukan ciri gelembung telah diperhatikan dan dianalisis berdasarkan bilangan gelembung bernukleus dan kekerapan keluar gelembung. Setiap tetapan eksperimen dilakukan tiga kali. Didapati bahawa SR dan suhu mempengaruhi kadar penyahairan SBH dengan ketara. Kadar penyahairan tertinggi sebanyak 0.42 %/min diperolehi pada permukaan paling kasar 11.33 µm dan suhu tertinggi 50 °C. Ia adalah lima kali lebih pantas berbanding dengan kadar penyahairan pada 0.80 µm SR 40 °C, iaitu hanya 0.08 %/min. Kadar penyahairan tertinggi diperoleh pada SR tertinggi disebabkan oleh lebih banyak tapak nukleasi, dengan itu meningkatkan bilangan buih yang berlepas. Dengan mengasarkan permukaan pemanas, pekali pemindahan haba (HTC) dipertingkatkan kerana lebih banyak rongga dan tapak nukleasi terdapat pada permukaan. Permukaan 11.33 µm menghasilkan 143 % lebih tinggi HTC daripada 0.80 µm. Di samping itu, kadar penyahairan tertinggi diperoleh pada suhu yang lebih tinggi kerana penyebaran dan pemindahan haba lebih baik pada suhu yang lebih tinggi berbanding dengan suhu yang lebih rendah. Ini kerana apabila suhu meningkat *q”*, kekerapan gelembung keluar dari permukaan pemanas dan HTC juga meningkat. HTC maksimum yang diperoleh adalah sekitar 10.11 kW/m^{2}K, sepadan dengan suhu tertinggi yang diuji pada 50 °C. Oleh itu, SR dan suhu yang lebih tinggi menghasilkan kadar penyahairan yang lebih tinggi, dan ini dikaitkan dengan pertambahan tapak nukleasi, kekerapan gelembung berlepas dari permukaan pemanas, *q″,* dan HTC.

ABSTRACT

One of the issues faced by stingless bees beekeepers is related to the storing of Stingless Bees Honey (SBH) at room temperature. This is because SBH contains high water content which may cause fermentation. Hence, the dewatering process is necessary to reduce the water content and prevent fermentation. The conventional methods that are used to lower the water content of honey are not efficient and have the potential to degrade the nutritious content of honey. Thus, the Low Temperature Vacuum Drying with Induced Nucleation Boiling (LTVD-NB) method has been developed to solve the problem of honey dewatering efficiency while maintaining honey quality. As LTVD-NB method involve with nucleate boiling, therefore surface roughness (SR) and dewatering temperature could affect the performance of dewatering honey. However, research on the effect of SR and dewatering temperature on nucleate boiling is limited. It is known that SR determines cavity and affects boiling heat transfer process, whereas temperature determines heat flux (*q"*). It is believed that boiling heat transfer process is directly related to bubble nucleate on heated surface. However, there is a limited amount of research available on the effect of SR and dewatering temperature towards the characteristics of bubble nucleation in honey. Thus, the objective of this study was to investigate the effects of temperature and SR of stainless steel heater pipes on dewatering rate, nucleate boiling heat transfer (NBHT), and bubble nucleate characteristic during dewatering of SBH. 200 g of SBH sample was heated for five minutes at three different temperatures, which were 40, 45, and 50 °C using stainless steel heater pipes with SR of 0.80, 3.39, 8.82, and 11.33 µm at the pressure of 5 kPa. A digital camera was used to capture and record the formation of bubble nucleate on the heater surface during the experiment. The formation of bubble characteristic has been observed and analysed base on the number of bubble nucleated and the bubble departure frequency. Each experimental setting was performed three times. It was found that SR and temperature significantly affected the dewatering rate of SBH. The highest dewatering rate of 0.42 %/min was obtained at the roughest surface of 11.33 µm and highest temperature of 50 °C. It was five times faster compared to dewatering rate at 0.80 µm SR of 40 °C, which was only 0.08 %/min. The highest dewatering rate was obtained at the highest SR due to more nucleation sites, thus increased the number of bubbles depart. By roughening the heater surface, the heat transfer coefficient (HTC) was enhanced as more cavity and nucleation site were present on the surface. The 11.33 µm surface produced 143 % higher HTC than the 0.80 µm. In addition, the highest dewatering rate was obtained at higher temperature as the heat dispersion and transfer were better at higher temperature compared with lower temperature. This is because as temperature increased *q"*, bubble frequency departure from heater surface and HTC also increased. The maximum HTC obtained was around 10.11 kW/m^{2}K, corresponding to the highest temperature tested at 50 °C. Thus, higher SR and temperature resulted in higher dewatering rate, and this correlated with the increment of nucleation site, bubble frequency depart from heater surface, *q"*, and HTC.

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