Simulation of a Vacuum Evaporator for Propolis Production

Y Muharam, M Sahlan, Tiarrahman and S P Aletheia

1Department of Chemical Engineering, University of Indonesia, Depok 16424, Indonesia

E-mail: muharam@che.ui.ac.id

Abstract. Propolis is a matter produced by honey bees. Propolis production is carried out through extraction with ethanol and dilution with water. In order to increase the propolis purity, ethanol and water need to be removed in the final product by vacuum evaporation. The evaporation process that has been utilized so far has not been able to regenerate ethanol properly and the propolis production capacity is yet in small amounts, so an optimization of evaporation process needs to be performed to increase the propolis production. The purpose of this study is to obtain an optimum condition of a vacuum extraction for propolis production. The method used is the numerical simulation of the extraction process that has been modeled mathematically. The model consists of mass balance, energy balance and momentum balance. The simulation results for the evaporator of 0.35 m in diameter and 0.18 m in fluid height show that the optimum condition is at 343 K and 5x10^-3 atm with the evaporation time being about 13 hours.

1. Introduction

The diversity of Indonesia’s natural resources is an advantage that can be utilized optimally to provide solutions to economic problems for the community. One type of the utilization of natural resources that has been known to have many benefits and is being developed recently is propolis. Propolis is a matter produced by honey bees and serves to patch and sterilize honeycombs [1]. Propolis is discovered to have diverse benefits for human health such as antiviral, antifungal, antibacterial activities [2] and as antioxidants [3]. Considering its great benefits for health and its extensive development, propolis is very potential to be developed in Indonesia. Moreover, most of the domestic demand of propolis is yet fulfilled through imports, even though Indonesia has abundant raw materials.

Sahlan [4] has developed the process of propolis production by extraction with 96% ethanol, then vacuum evaporation at 65 °C to remove ethanol, and then at 80 °C to remove water. However, the process has several drawbacks, which must be eliminated. One of which is that ethanol cannot be regenerated properly because most of ethanol is evaporated with water. The difficulty in regenerating ethanol happened because the evaporator unit did not operate optimally. For that reason, the development of an evaporator unit for removing ethanol and water should be carried out so that their concentration in the final product are in accordance with the specifications. The purpose of this study is to obtain an optimum condition of a vacuum extraction for propolis production. The method used is the computer simulation of the extraction process that has been modeled mathematically.
2. Methodology
The simulation software used in this paper is COMSOL Multiphysics, a computational fluid dynamics-based program.
The model consists of mass balance, energy balance, momentum balance, and mass and energy fluxes at the boundary layer.
The energy balance, the mass balance and the momentum balance is described by Equation (1), Equation (2) and Equation (3), respectively:

\[ \rho \rho C_p u \nabla T = \nabla \cdot (k \nabla T) + Q \]
\[ \nabla \cdot j_i + \rho (\vec{u} \cdot \nabla) \omega_i = R_i \]
\[ \rho (\vec{u} \cdot \nabla) \vec{u} = -\nabla p I + \nabla \left[ \mu (\nabla \vec{u} + (\nabla \vec{u})^T) - \frac{2}{3} \mu (\nabla \cdot \vec{u}) I \right] + F \]

The mass flux at boundary layer is as follows:

\[ N_A = k (c_{AI} - c_{AB}) \]
\[ N_B = k (p_{AB} - p_{AI}) \]

The mass transfer coefficient is predicted using Sherwood number:

\[ R_e = \frac{\rho v L}{\mu} \]
\[ S_c = \frac{\rho}{\rho_{AB}} \]
\[ S_h = 0.332 R_e^{1/2} S_c^{1/3} \]
\[ S_h = \frac{k L}{D_{AB}} \]

The energy flux at boundary layer is described by:

\[ q = h(T_{ext} - T) \]

The energy transfer coefficient is obtained using Nusselt number:

\[ Pr = \frac{C_p \rho}{k} \]
\[ Nu = 0.332 R e^{1/2} P r^{1/3} \]
\[ Nu = \frac{h L}{k} \]

The vapor-liquid equilibrium and the fluid properties such as density were obtained from references [5], [6], and [7].
3. Results and Discussion

3.1. Temperature profile

Based on the developed operating conditions of propolis production processes, the simulation process is carried out in the operating temperature range of 338K to 358K. The temperature profile of the evaporator at a specific time range at heating temperature of 343K is presented in Fig 2. The gas phase temperature rises slower than the liquid phase temperature, due to liquid heating at the bottom of the evaporator prior to the component boiling point and evaporation heat. Isolated system affecting the temperature profile uniformity in the evaporator after 6 hours of heating (Fig 2).

Fig 2. Temperature profile

3.2. Velocity profile

Velocity profile illustrates momentum balance distribution in the vacuum which gas flows from the higher pressure at the interface boundary layer towards the outlet. The vacuum process has no effect to liquid velocity, due to more significant diffusion process in liquid mass transfer, which caused the velocity profile approaches zero (Fig 3). The initial velocity of gas phase is about $2.6 \times 10^{-3}$ m/s, and decreasing through time, and eventually approaching zero as liquid phase and gas phase reaches equilibrium state, where mass transfer occurs in microscopic scale.

Fig 3. Velocity profile

3.3. Ethanol reduction profile

Decreasing of ethanol composition in evaporator through time is presented in Fig 4. Significant decrease of ethanol composition occurs in the first 5 hours, while becoming more constant afterwards. However, vacuum state drives ethanol to evaporate and transfer in microscopic scale. In the other hand,
there is no significant loss of ethanol in liquid phase, and vacuum state did not affect the liquid ethanol composition profile. From the simulation results it is known that the process of mass transfer from the liquid phase to the gas phase is very small. This small mass transfer occurs because the mass transfer process only in diffusion way and there is no convective mass transfer. It can be seen from the velocity profile in Figure 4 shows the velocity in the liquid phase close to zero. Diffusion process occurs because the random movement of molecules due to the influence of heating or intermolecular energy transfer due to the temperature gradient and pressure gradient [8]. Diffusivity coefficient of liquid about $10^{-10}$ to $10^{-9}$ m$^2$/s, compare to the gas diffusivity coefficient of $10^{-6}$ to $10^{-5}$ m$^2$/s, it is seen that if the mass transfer process occurring only by diffusion way, the liquid will be more difficult to evaporate.

![Fig 4. Decrease in ethanol concentration in (a) gas phase (b) liquid phase](image)

3.4. Effect of evaporation time to ethanol reduction profile

Ethanol reduction profile with the function of evaporation time in liquid phase (Fig 5) and gas phase (Fig 6) are shown in graphs. The decrease of ethanol shows nothing significant in both liquid and gas phase. When evaporation process did up to 13 hours, ethanol was decreased until 0.056, but down to 0.04304 after 16 hours. This is caused by equilibrium state that had been reached, so that the mass transfer process occurred in microscopic scale.

![Fig 5. Effect of evaporation time to ethanol fraction in liquid phase](image)
3.5. Pressure effect

Fig 7 and Fig 8 show the variation of the mass fraction to the variation of pressure at overall system, performed at pressure $10^{-1}$ atm to $5 \times 10^{-3}$ atm. Ethanol composition in liquid phase did not able to decrease significantly to the increase of pressure (Fig 7). While in the gas phase, vacuum process at $5 \times 10^{-3}$ atm able to reduce the composition of ethanol as close as to zero.
3.6. Temperature effect

The optimum temperature to evaporate ethanol based on the simulation is 353 K, where the mole fraction of ethanol decreased to 0.032. This significant decline at 351 K, atmospheric pressure, occurred because ethanol has reached its boiling point. At 353 K, ethanol has evaporated completely. At 358 K, ethanol left the evaporator column significantly until 11,834 seconds, after which ethanol composition began to increase. This occurred because water reached its boiling point at 358 K, at which a small portion of water began evaporating, leaving the evaporator columns. Because these calculations using the mole fraction, when water began to decrease, ethanol or glycerol fraction will go up, keeping the total mole fraction unity.

\[ T_B = \left( \frac{R[\ln(P_0) - \ln(101.325)]}{\Delta H_{\text{vap}}} + \frac{1}{T_0} \right)^{-1} \]  

(15)

Based on the Clausius-Clapeyron equation, the ethanol pressure at 5x10^{-3} atm reached the boiling point temperature at 338 K, and reached vapor phase at 343 K. This is the optimum temperature to decrease the ethanol composition.

![Graph showing temperature effect on ethanol mole fraction](image)

Fig 9. Temperature effect on ethanol mole fraction

4. Conclusion

The result of the simulation lead to the following conclusion:

- Simulating the temperature variations in the range of 338K-358K, obtained optimum operating conditions to evaporate ethanol at a temperature of 343K.
- Simulating the pressure in the range 5x10^{-1} to 1x10^{-3} atm, obtained the optimum vacuum pressure at 1x10^{-3} atm.
- Variation of evaporation time from 11 hours to 16 hours, obtained optimum evaporation time at about 13 hours
- Higher temperatures accelerated the evaporation process, but due to the propolis active components are easily damaged at high temperatures, it is necessary to make evaporation process at low temperature by lowering the pressure of the system through a vacuum system.
- Addition of evaporation process did not evaporate solvent significantly, caused by equilibrium state of the system, so that the mass transfer occurs on a microscopic scale.

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