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Pressure Effect on Heat Transfer Characteristics of Vacuum Evaporator System in Sugarcane Sap Concentration Process

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ABSTRACT

The largest energy consumption in sugar factories is used for heating sap by evaporator, so this study will investigate the effect of vacuum pressure and process time on increasing °Brix content using vacuum evaporator. This research aims to analyze thermal mass transfer, energy distribution and specific energy consumption. The results showed that vacuum pressure affects the evaporation rate. At ΔP = 350 mmHg (0.46 atm) and 240 minutes the amount of water evaporated was 5.08 kg or (average = 1.27 kg/hour), for ΔP = 550 mmHg (0.72 atm) with water evaporated was 6.48 kg (average 1.620 kg/hour) and for ΔP = 570 mmHg (0.75 atm) was 6.5 kg. (average = 1.625 kg/hour). The highest rate of evaporation was at time duration of 240 minutes with a vacuum pressure of 570 mmHg amounting to 6.8 kg. Process time also affects the consumption of electrical energy used. The optimum condition for the evaporation process using a double jacket evaporator is at the duration of 180 minutes, pressure 550 mmHg (0.72 atm) and 570 mmHg (0.75 atm). In this condition, the °Brix value is 74 to 79. Specific energy consumption is 1.40 kwh/kg product and thermal efficiency 54.20% at pressure 570 mmHg. This research contributes to energy efficient thermal diffusion separation technology.

Keywords: *Evaporation, Vacuum Evaporator, Sugarcane Sap, Brix, Energy Consumption*

1. INTRODUCTION

The role of energy in human history is crucial as it is one of the necessities of human life. One of the large-scale energy operation processes in industry is the evaporation process. One of the purposes of the evaporation process is to reduce the moisture content and weight of liquid materials [1]. Energy consumption in sugar factories is mostly used for sap heating, evaporation, and crystallization to support the production process. Evaporation is emphasized in the thermal integration aspect because it is the process with the largest energy consumption. The evaporation process occurs when the heating medium in the oil jacket heats the clear sap in the evaporator tank. The water content in the sap will be evaporated by the heat from the oil jacket. The sap then thickens while the water vapor from the sap will be condensed into condensate.

The production of liquid sugar commodities at the household industry level usually uses a conventional evaporation process. Conventional equipment with high temperatures and long time, thus triggering damage to the produced product and leading to high energy consumption. To reduce any risk of material damage due to thermal effects in the evaporation process, a vacuum evaporator can be used so that the boiling point of the solvent can be lowered.

The utilization of low temperatures along with vacuum conditions will keep the nutrition of the product from losing its value [2]. One of the factors that affect the evaporation process in vacuum evaporators is vacuum pressure and evaporation rate. Vacuum pressure is a vacuum condition that occurs in the evaporation chamber resulting from the operation of the vacuum pump in the evaporator. Vacuum pressure measurement is performed by observing a pressure gauge installed at one point in the evaporation chamber [3]. The evaporation rate in the vacuum evaporator can be determined by decreasing the moisture content of the material.

According to the work conducted by Wiyono et al. [4], the performance test of a vacuum evaporator to produce liquid palm sugar was carried out at a vacuum pressure of 0.25 atm in 9 hours and 40 minutes, resulting in liquid sugar products with a concentration of 80% and a reduction in water content in the product of about 21% according to the standard of liquid sugar set by the draft standard of liquid sugar (SNI 01-2978-1992). Based on research by Muhlisin [5] in thickening sugar cane juice into brown sugar using a vacuum evaporator with a

temperature of 80 °C, the average energy requirement is 10,876.32 kJ.

Some previous studies still use relatively high operating conditions, such as using temperatures in the 80 °C range and a relatively long evaporation time of about 9 hours. The high temperature and long evaporation time impact high energy consumption. Therefore, in this research, the process of concentrating sugarcane sap will be carried out with a vacuum evaporation system. In this way, the operating time can be shortened and the operating temperature can be lowered, so that energy consumption can be reduced and product quality can be maintained.

2. MATERIAL AND METHODS

This research investigates the concentration of sugarcane juice at low temperatures using a set of vacuum evaporator equipment. The preparation and implementation of the research was carried out for five months, starting in March 2023 and ending in July 2023. The output of this research is a concept of thermal diffusion separation technology that can be applied for practical learning purposes at the vocational higher education level and commercial purposes.

2.1 Material

The raw material used for this experiment is 150 kg of sugarcane sap used for 15 run times, every run used 10 kg of sugar cane sap. The equipment used for the study is a vacuum evaporator with a capacity of 15 kg.

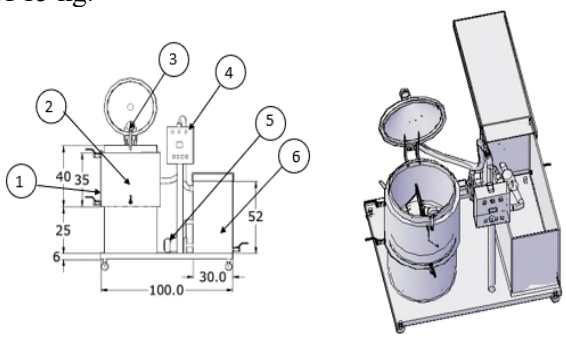

Figure 1. Vacuum Evaporator

2.2 Methods

As the object of this research, sugarcane sap with an initial concentration of 30% was used. The evaporation process was carried out at vacuum pressure below atmosphere. The pressure treatment consisted of three experimental levels, i.e. 350 mmHg (0.46 atm), 550 mmHg (0.72 atm) and 570 mmHg (0.75 atm). The treatment of process time consisted of five experimental levels, i.e. 60 minutes, 180 minutes and 240 minutes. Each treatment used 10 kg of sap with the same initial concentration of 30%. The process variables that will be measured and observed are the measurement pressure, process time, the amount of water that is completely evaporated and Brix concentration of the sap. Raw data from the results of measurement and observation are then compiled in the form of tables and analyzed to determine the interaction relationship between variables.

2.3 Flow Diagram of Research Process

This research process can be observed in the following diagram.

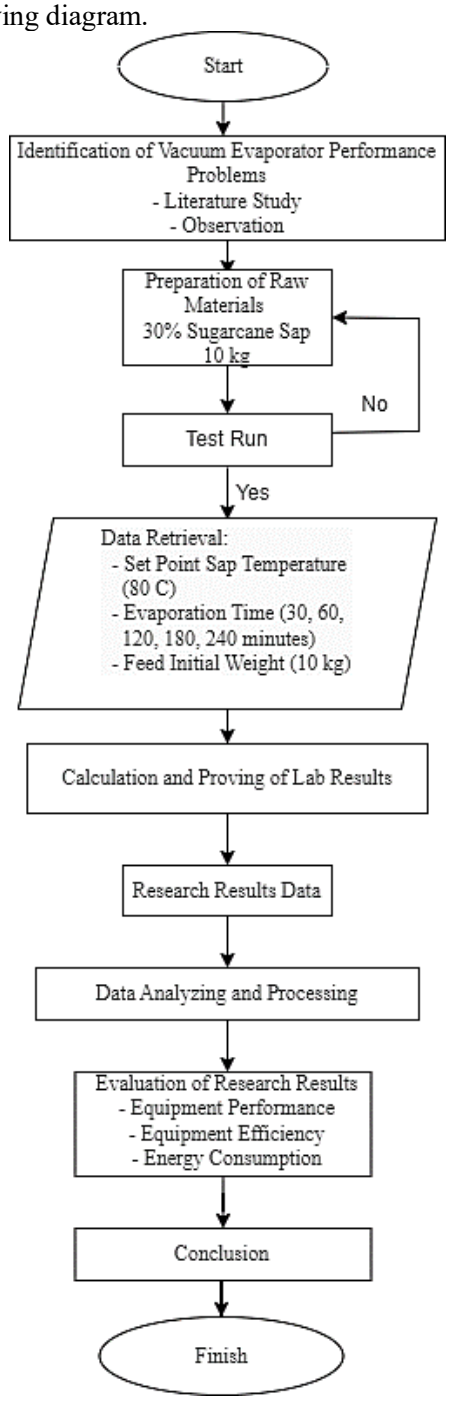

Figure 2. Flow Diagram of Research

3. RESULTS AND DISCUSSIONS

The process of evaporation or sap concentration is carried out using a set of vacuum evaporator equipment with a capacity of 15 kg. The heat source comes from an electric fine tube heater with a power of 3000 watts. Centrifugal vacuum pump with 175 watts power serves to condition the vacuum chamber and stirring motor with ¼ HP power set at 90 rpm, serves to maintain the temperature of the solution to remain uniform. Variable interactions that will be discussed in this study.

3.1 Effect of Evaporation Time on Brix Degree

The aqueous sap solution as the object of research has an initial moisture content of 30% or with a brix value of 30. The evaporation process begins with a duration of 30 minutes. During this time, the observation showed that the water content increased for all operating conditions. In condition 1 (pressure 350 mmHg) there was an increase in brix value from 30 to 61. In condition 2 (pressure 550 mmHg) there was an increase from 30 to 85, and in condition 3 (pressure 570 mmHg) it increased to 88. Overall, the brix value increased from 30 to 240 minutes. Visually, the trend of increasing brix value can be seen in Figure 4 below.

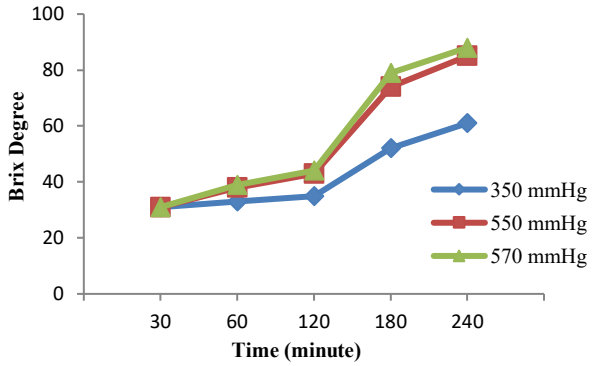

Figure 4. Effect of Evaporation Time on Brix Degree

From Figure 4, 3 trends display the mathematical pattern of changes in brix content over time, with the first 30 minutes showing the lowest brix content and the 240 minutes showing the highest brix content. It can be interpreted that the evaporation time is very influential in increasing the brix value. So, sap with a high brix will give a thick yield with a high sucrose content, thus reducing the water content and improving the consistency [6].

3.2 Effect of Vacuum Pressure on Water Removal

The evaporation rate is the rate of reduction in the water content of the material due to the evaporation process of evaporation through heating in a certain time [7]. As time goes by in the evaporation process, the amount of water removed will increase. However, this is inseparable from the influence of vacuum pressure which is the selected operating system. At a pressure of 350 mmHg, the vacuum evaporation process can remove 50.8% of the water content within 4 hours, while at vacuum pressures of 550 mmHg and 570 mmHg, 64.8% and 65% of the water can be removed, respectively. In other words, the lower the pressure of the evaporation system, the faster the water is evaporated. This is acceptable, as the boiling point of water decreases directly proportional to the decrease in pressure. The pattern is visually displayed in Figure 5 below.

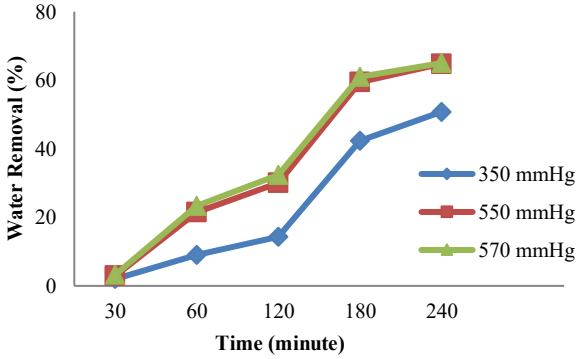

Figure 5. Effect of Vacuum Pressure on Water Removal

From Figure 5, it is known that the lowest trend is at a pressure of 350 mmHg and the highest trend is at a pressure of 570 mmHg. This means that the highest water removal is at a trend of 570 mmHg and applies to a time range of 30 to 240 minutes.

3.3 Effect of Operating Conditions on Energy Consumption

Operating time is a highly significant variable in determining the amount of energy consumption as it relates to efficiency and operating costs. The analysis of the calculation of specific energy consumption (SEC) in the period of 240 minutes is the optimum condition to obtain the value of concentrated sap brix (60 to 80) according to SNI 2891-1992. In that period, the specific energy consumption obtained for each operating condition is 0.99 kWh/kgH_2O at vacuum pressure 350 mmHg, 1.64 kWh/kgH_2O at 550 mmHg, and 1.66 kWh/kgH_2O at 570 mmHg. This means that the operating conditions (2) and (3) in the time range (180 to 240) have met the standard brix sap. Specific energy consumption (SEC) for each pressure and time is 1.33 kWh/kg sap at pressure - 550 mmHg, duration time 180 minutes, and 1.64 kWh/kg sap for duration time 240 minutes. At vacuum pressure 570 mmHg with a duration time of 180 minutes SEC

1.40 kWh/kg sap was obtained and for a duration time of 240 minutes SEC 1.66 kWh/kg sap. Thus, the optimum operating conditions were achieved in 180 minutes at operating pressures of 550 mmHg and 570 mmHg.

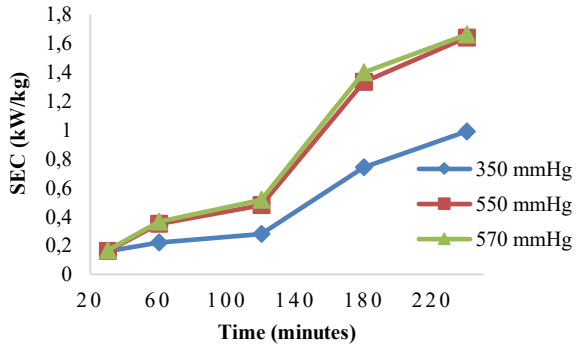

Figure 6. Effect of Operation Time on SEC

4. CONCLUSION

From the study performed, it can be concluded that the higher the vacuum pressure, the more significant the evaporation rate will be. It can be seen that at ΔP = 350 mmHg in 240 minutes the amount of water evaporated was 5.08 kg or (average = 1.27 kg/hour), at the same time for ΔP = 550 mmHg the amount of water evaporated was 6.48 kg (average 1.620 kg/hour) and for ΔP = 570 mmHg was 6.5 kg. (average = 1.625 kg/hour). The longer the evaporation time, the higher the evaporation rate. The most evaporation in 240 minutes with vacuum pressure 570 mmHg amounted to 6.5 kg. Thus, time and vacuum pressure greatly affect the evaporation rate.

Process time also affects the consumption of electrical energy used. The longer the process time, the greater the electrical energy used. The optimum condition for the evaporation process using a double jacket is at a duration of 180 minutes (3 hours), pressure 550 mmHg and pressure 570 mmHg. In this condition, the brix value is 74 to 79. SNI brix standard for sugar factory juice is 60 to 80.

Based on the calculations that have been done, the Specific energy consumption (SEC) value of 1.40kWh/kg product and thermal efficiency of 54.20% at vacuum pressure 570 mmHg are obtained. So, it is known from this study, that the operating cost for the sugar cane sap concentrating process is Rp.1960, -per kg. (TDL = Rp.1400,00 per kWh).

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