Development of drying machine to improve palm sugar quality

Erwin Erwin\textsuperscript{1,3}\textsuperscript{*}, Meutia\textsuperscript{2,4}

\textsuperscript{1} Mechanical Engineering Department, Universitas Sultan Ageng Tirtayasa
\textsuperscript{2} Agribusiness departemen, Universitas Sultan Ageng Tirtayasa
\textsuperscript{3} Renewable energy research laboratory, Universitas Sultan Ageng Tirtayasa
\textsuperscript{4} Indonesia center of excellence for food security (local food innovation), Universitas Sultan Ageng Tirtayasa

\textsuperscript{*}Email: erwin@untirta.ac.id

Abstract. One variant of palm sugar products is sugar in the form of powder or often called brown sugar, which is of good quality is bright yellow sugar, with a strong special aroma and a uniform and dry crystal size according to (Indonesian nation standardized) SNI 01-3743-1995 maximum allowable water content is 3\%. An artificial drying machine is needed to speed up the process of separating the water content in sugar. This machine is designed with a tiered rack with a heating source. The temperature regulation uses thermostat, the way it works is by electrically charged elements to heating air, and directing hot air into the drying chamber by using fan (fan blower) and (exhaust fan) for air circulation. The quality to be achieved in the experiment is sugar with a maximum water content of 3\%. Experiments were carried out several times with brown sugar that has been matched in grain size. Drying time is very important, because this time is related to production capacity and energy consumption. The remaining water content is less than 3\% according to the needs of the planning, the tool is functioning properly.

1. Introduction

Palm sugar is one of the commodity products in Lebak-Banten district whose production has penetrated national and international markets, with export volumes reaching 30 tons per month. And according to data from the district's industry and trade service, the number of palm sugar makers is 5,815 units.

Good quality palm sugar, which has a bright yellow color, has a strong characteristic aroma and a uniform and dry crystal size according to the SNI 01-3743-1995 quality standard. The maximum permissible water content is 3\% [1]. Based laboratory test on palm sugar contains water ranges from 4.29\% by weight of sugar.

There are two ways that can be used, the first by drying in the sun the advantages of this method is cheap from the cost of unnecessary expensive support, and the drawback is the amount of heat obtained is not fixed so long drying time is difficult to predict, ant sugar can be contaminated with wind-borne dust, and also requires a large area.

The second method with an artificial dryer (oven) excess temperature can be controlled, cleanliness is maintained and the heat obtained remains unaffected by weather conditions so that the drying time
can be predicted, the shortage of this method is the need for additional costs for the manufacture and operation of the equipment.

This research aims to produce a product that can reduce the water content of palm sugar so that it can meet the requirements of SNI standards, and export standards.

2. Research Methodology
When the drying process takes place evaporation of water from the sugar granules, the water moves to the surface. The mechanism of movement of water affects drying during periods of constant drying rate and when the drying rate decreases [2]. There are three forms that explain the rate of drying figure 1:

![Drying Rate Curve](image)

**Figure 1.** Drying speed curve

To determine the moisture content of the material determined based on dry weight (dry basis) and wet weight (wet basis). Calculation of water content (wet basis) can be formulated as follows:

\[
M_{wb} = \frac{(W_1 - W_2)}{W_1} \times 100\%
\]

Where:
- \( M_{wb} \) = water content (%)
- \( W_1 \) = Wet Sugar Weight
- \( W_2 \) = Dry sugar weight

To find out the dry basis water content, formula is used:

\[
M_{db} = \frac{(100 \times M_{wb})}{(100 - W_{wb})}
\]

2.1. Heat for drying
When the heat energy is received or released by a substance, then the object will experience two things, namely changes in temperature and form. An increase in temperature on an object can be determined using an equation that relates to the specific heat or heat capacity.

Drying load of sugar is calculated by the equation below:

\[
Q_{tot} = Q_1 + Q_2 + Q_3 + \ldots + Q_n
\]

\[
Q_1 = m_k \cdot C_p \cdot \Delta T
\]
To measure the amount of heat needed for evaporation of water in ant sugar, the following equation is used:

\[ Q_2 = m_a \cdot C_a \cdot \Delta T \]  

(5)

determine the amount of heat given by the heating air to the dried material used in the equation:

\[ Q_3 = m_{\text{water} \rightarrow \text{steam}} \cdot h_{fg} \]  

(6)

To determine the drying efficiency used equation:

\[ \eta = \frac{Q}{q} \times 100\% \]  

(8)

while the equation to find out the amount of heat needed during drying is:

\[ q = \rho \cdot v \cdot C_a \cdot (T_1 - T_2) \]  

(7)

To find out the drying mass rate, a formula is used:

\[ m_{\text{adara}} = \rho \times Q_{\text{debit}} \]  

(10)

while the formula for calculating total energy is used

\[ E_{\text{total terpakai}} = E_{\text{elemen}} + E_{\text{kipas}} \]  

(11)

Heat for drying can come from heating elements that use electricity or use heat from other sources such as renewable energy [3].

2.2. Drier design and testing

The dryer must be designed to fulfill the function so that the work process runs smoothly and in line with expectations. There are 4 systems that must be designed, namely the frame, heater, drying chamber and air circulation unit. The frame design is made as shown below:

Figure 2. Drying machine rack design

In designing the product specification target is the capacity of drying is ± 100 kg / hour, the available electric power is limited to 900 watts, and is able to reduce water content up to 3% for 60 minutes per batch.
From the results of laboratory tests, it is known that the percentage of water content is wet sugar base ($m_b$) = 4.29\% and dry ($m_k$) = 2.84\%. To find out the mass of palm sugar can be found by the equation (for 100gr sugar):

$$p = \frac{m}{v} \quad (12)$$

so: $$p = \frac{100}{109,65} = 0,911 \text{ gr/cm}^3$$

and to find out the mass of sugar water content that must be evaporated ($m_{\text{water}}$) the 9 kg trial material is as follows:

amount initial water mass = \frac{4,29}{100} \times 9 \text{ kg} = 0,386 \text{ kg}

$m_k = 9 \text{ kg} - 0,386 = 8,614 \text{ kg}$

sugar weight for 2,84\% = \frac{8,614 \times 100}{100 - 2,84} = \frac{861,4}{97,16} = 8,865 \text{ kg}$

$M_{\text{water steam}} = 9 - 8,865 \text{ kg}$

$M_{\text{water steam}} = 0,135 \text{ kg}$

For a drying load of 30 kg:

Initial water mass = \frac{4,29}{100} \times 30 \text{ kg} = 1,287 \text{ kg}

Dry weight = 30 \text{ kg} - 1,287 = 28,713 \text{ kg}

Final water weight 2,84\% = \frac{28,713 \times 100}{100 - 2,84} = \frac{2871,3}{97,16} = 29,55 \text{ kg}$

$M_{\text{water}} = 30 - 29,55 \text{ kg}$

$M_{\text{water steam}} = 0,45 \text{ kg}$

Calculate the drying heat energy requirements.

**Design specification:**
- Weight of dried sugar = 9 kg
- Drying air temperature = 60\°C
- Sugar end temperature = 54 \°C
- Outlet air temperature = 53 \°C
- Air speed = 150 Cfm
- sugar specific heat = 0,9072 \text{ kj/kg. \°C}
- initial water percentage = 4,29\%
- expected water percentage = 2,84\%
- time = 60 minutes

• Sensible heat calculation of sugar ( $Q_1$ )

$$Q_1 = m_k \cdot C_p \cdot \Delta T \quad (12)$$
Calculation of the sensible heat of water in sugar \((Q_2)\)

\[
Q_2 = m_a \cdot C_a \cdot \Delta T
\]  

(13)

Calculation of heat for evaporation \((Q_3)\)

\[
Q_3 = m_{water \rightarrow steam} \cdot hfg
\]  

(14)

Heat absorbed by the wall heater tube \((Q_4)\)

\[
Q_4 = m_{tube} \cdot C_{tube} \cdot \Delta t
\]  

(15)

Heat absorbed by the glass wall \((Q_5)\)

\[
Q_5 = m_{glass} \cdot C_{glass} \cdot \Delta t
\]  

(16)

Heat absorbed by the tray plate \((Q_6)\)

\[
Q_6 = m_{tray} \cdot C_{tray} \cdot \Delta t
\]  

(17)

Heat absorbed by the drying frame \((Q_7)\)

\[
Q_7 = m_{kp} \cdot C_{kp} \cdot \Delta t
\]  

(18)

The total need for drying heat is:

\[
Q_{tot} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7
\]  

(19)

\[
Q_{tot} = 187,55 \text{ kj} + 38,9 \text{ kj} + 326,565 \text{ kj} + 19,8 \text{ kj} + 10,75 \text{ kj} + 24,19 \text{ kj} + 86,4 \text{ kj}
\]

\[
Q_{tot} = 694,155 \text{ kj} = 92.77 \text{ watt/hours}
\]

Mass drying rate:

\[
M_{air} = \rho \times Q_{rate}
\]  

(20)

The heat supplied by air for the evaporation of material water:

\[
q = \rho \cdot V \cdot c_v \cdot (T_1 - T_0)
\]  

(21)

So to find out the amount of heat during drying are :

\[
q = Q_{tot \text{ drying}} \times t
\]  

(22)

Drying efficient

\[
\eta = \frac{\text{the amount of heat used}}{\text{heat given by air}}
\]  

(23)

Total energy used

\[
E_{total \text{ used}} = E_{heater} + E_{fan}
\]  

(24)

If the rack is full of 30kg wet sugar, the drying load is:

\[
Q_1 = m_k \cdot C_p \cdot \Delta T
\]  

(25)

30kg load divided by 10 shelves

\[
Q_1 = 28,713 \text{ kg} \cdot 0,9072 \text{ kj/kg} \cdot \text{C} \cdot (52-30)\text{C}
\]

\[
Q_1 = 573,06 \text{ kj}
\]

\[
Q_2 = 1,287 \text{ kg} \cdot 4,2 \text{ kj/kg} \cdot \text{C} \cdot (54-30)\text{C}
\]

\[
Q_2 = 128 \text{ kj}
\]

\[
Q_3 = 0,45 \text{ kg} \cdot 2419 \text{ kj/kg}
\]
\( Q_3 = 1088.55 \text{ kj} \)

- The total need for drying heat is:
  \[ Q_{\text{tot}} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 \]
  \[ Q_{\text{tot}} = 573.06 \text{ kj} + 128 \text{ kj} + 1088.55 \text{ kj} + 19.8 \text{ kj} + 10.75 \text{ kj} + 24.19 \text{ kj} + 86.4 \text{ kj} \]
  \[ Q_{\text{tot}} = 1930.75 \text{ kj} \]
  \[ = 536.11 \text{ watt/hours} \]

- Total drying time for 30 kg sample:
  Known load 9 kg and range time is 60 minutes
  Average time per shelf \( \frac{60}{3} = 20 \) minutes
  30 kg load divided by 10 shelves \( = 20 \times 10 \)
  \[ = 200 \text{ minutes} = \frac{200 \text{ minutes}}{60 \text{ minutes/hours}} \]
  \[ = 3.3 \text{ hours} \]

- So to find out the amount of heat during drying is:
  \[ q = Q_{\text{tot, drier}} \times t \]  \hspace{1cm} (26)
  \[ q = 536.11 \text{ wh} \cdot 3.3 \text{ hours} \]
  \[ q = 1769.16 \text{ watt/hours} \]

- Efisiensi pengeringan
  \[ \eta = \frac{1769.16}{6.36 \text{ m}^3/\text{s} \cdot 200 \cdot 60} \times 100\% \]
  \[ = 2.31 \% \]

And to reduce heat losses due to leakage, every corner of the connection, air gap as much as possible to be closed with silicon glue.

**Table 1. Heat absorbed when drying 9kg**

| Heat absorbed                          | Amount   |
|----------------------------------------|----------|
| Heat to heat sugar (Q₁)                | 187.55 kJ|
| Heat to heat water in sugar (Q₂)       | 38.9 kJ  |
| Heat to evaporate water (Q₃)           | 326.565 kJ|
| The heat absorbed by the heater tube (Q₄)| 19.8 kJ |
| Heat absorbed by the glass wall (Q₅)   | 10.75 kJ |
| The heat is absorbed by the tray plate (Q₆)| 24.19 kJ|
| The heat absorbed by the drying frame (Q₇)| 86.4 kJ |
| Total heat absorbed (Qtot)             | 694.155 kJ|

**Table 2. Heat absorbed when drying 30 kg palm sugar**

| Heat absorbed                          | Amount   |
|----------------------------------------|----------|
Heat to heat sugar ($Q_1$) 1079,665 kJ
Heat to heat water in sugar ($Q_2$) 128 kJ
Heat to evaporate water ($Q_3$) 1088,55kJ
The heat absorbed by the heater tube ($Q_4$) 19.8 kJ
Heat absorbed by the glass wall ($Q_5$) 10.75 kJ
The heat is absorbed by the tray plate ($Q_6$) 24.19 kJ
The heat absorbed by the drying frame ($Q_7$) 86.4 kj
Total heat absorbed ($Q_{tot}$) 2437,355 kJ

3. Experiment Result
Each rack contains 3 kg of palm sugar with a water content of 4.3%, drying temperature is set at 60°C, and the result can be seen at table 3.

| No | Time (minutes) | Temperature reached (°C) |
|----|----------------|--------------------------|
|    |                | Rack 1 (lower) | Rack 2 (middle) | Rack 3 (upper) |
| 1  | 20             | 38            | 37            | 38            |
| 2  | 30             | 43            | 43            | 42            |
| 3  | 40             | 44            | 44            | 43            |
| 4  | 50             | 51            | 50            | 50            |
| 5  | 60             | 54            | 53            | 53            |
|    | Final weight (kg) | 2.954       | 2.955       | 2.955       |

Figure 3. Dried palm sugar

4. Result
The design of a palm sugar dryer has succeeded in reducing the water content from 4.3% to 2.95% in 60 minutes. There are some things that still need further development. Durability testing of the device also needs to be done to determine it’s resilient. Utilization of renewable energy can be done in the heating system as it is done in the liquid sugar evaporation process [4].

5. Reference
[1] BSN 1995 *Gula Palma*
[2] Geankoplis, C.J. 1983 *Transport processes: Momentum, heat and mass* United States: Allyn and Bacon Inc.
[3] Lusiani, R., A. Sudrajat, and Erwin 2019 Effect of air fuel ratio (AFR) on performance of gasification machine TG30-1 using water boiling test method on wooden powder biomass IOP Conference Series: Materials Science and Engineering 673 012123

[4] Listijorini, E. and S. Wiyono, 2019 Rice husk gasification performance to decrease water content in liquid palm sugar IOP Conference Series: Materials Science and Engineering 673 012121