Preliminary Evaluation of Kenaf Fibre Using Solar Drying Chamber

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***Abstract*—*High demand of kenaf or Hibiscus Cannabinus L motivates to enhance and secure the quality and consistency of producing premium grade of this natural fibre. Harvested kenaf will undergo several processes including decoating, retting, drying and storage. This research will be focusing on drying process by replacing the conventional method which is open drying, with solar drying. The solar dryer used in this research consists of evacuated tube collector, storage tank, electric heater, air handling unit and drying chamber. The test was conducted at Chuping Perlis with a total of 175.00 kg kenaf fibre is dried inside the drying chamber. Data was recorded using data-acquisition unit system model Graphtec GL820, including the information of ambient (solar irradiance intensity, relative humidity and temperature), drying chamber (inlet relative humidity, outlet relative humidity, inlet temperature and outlet temperature) and fibre (weight). Estimations of energy and exergies of drying chamber calculated, and determination of moisture extraction rate MER were done. The final weight of the kenaf fibre is 64.40 kg with average moisture content wet basis w.b reduces from 100.0 % to 36.8 % and MER also determined as 21.07 kg/hr.*

Keywords*—*kenaf fibre drying; solar thermal dryer; evacuated tube greenhouse drying chamber

I. Introduction

Kenaf or *Hibiscus Cannabinus L* is a short period and non-wood fibre crop. It can grow from 2 to 5 m tall. Kenaf also can be described as large, light yellow, bell-shaped flower with a widely open corolla. The flowers are 8 to 10 cm in diameter with five petals [1]. A review on kenaf in Malaysia has been divided into 5 sections: taxonomy and morphology, adaptability, management practice, processing and end-product [2]. Some issues such as deforestation and biodiversity preservation can be counter by introducing kenaf as an alternative as non-wood applications [2,3]. Fibre is one of the main products of kenaf. To produce fibre, the stem must go into several main processes including decoating, retting and drying. Decoating process separated the outer coarser layer part known as fibre and fine inner part known as core using decorticator machine. Retting process traditionally performed using dew and water retting. Chemical retting produces much cleaner fibre but low in physical strength, however, using enzyme results faster retting time, better quality but higher in cost [4]. Drying needed to remove moisture from the fibre, conventionally, open drying was used because it is easy to handle and more economical. Moreover, this method had its disadvantages such as time consuming, require large area, sunshine dependent and quality control problem due to ununiform drying, fungal problem and contamination from dust or animals [3,5]. At this point, the potential of the solar dryer become more significant. Solar dryer can also be modified and combined to produce the system that suitable for specific product and has been effectively used to dry various types of agricultural and sea product [6]. Thus, this system can enhance quality and faster drying process of kenaf.

Various researches conducted to study the drying process of kenaf. Misha et al [3] was using solar assisted solid desiccant to dry core kenaf. The drying process can be performed in low irradiance intensity and the drying time reduced 24 % compared to open sun drying to achieve 18 % moisture content. Seng and Teik [7] using the flatbed box with burner to dry kenaf leave and stem. This method achieved final moisture content around 8.3 %, thermal efficiency 33 – 46 % and average cost of RM0.46/kg water removed. Another method used by Ramli et al [8] is superheated steam to dry kenaf fibre. This method used readily available steam source in the kenaf factory and reduced moisture content almost 100 % in 15 minutes. Ling and Lin [9] experimented to dry kenaf seed using freeze dried method. The result shows larger pore size and prevents degradation of bioactive compounds compared to oven drying method. Drying kenaf stem by using oven drying was tested by Nazren et al [10], testing on microwave rectangular waveguide resonator to identify moisture content of kenaf but only suitable for small diameter cross section sample area. Mollah et al [11] using different drying time and threshing method to dry kenaf seed. The highest yield recorded at 7 days threshing time without drying process. Daniel et al [12] discussing about conventional open drying method to dry leave and stem. This is the most economical method but produced low quality of kenaf and exposed to contamination.

II. Material and Methodology

A. The Solar Dryer and Measurements

The aim of this experiment is to determine the energy and exergies of the solar drying chamber. The main component consists of the evacuated tube collector, storage tank, electric heater, pumps (primary and secondary pump), air handling unit AHU and drying chamber. Heat from the sun collected using the evacuated tube solar collector. Primary pump allow water to flow through the tube and the temperature will rise. Hot water then stored inside the insulated storage tank with internal electric heater. Secondary pump then allowed the water to flow to AHU. The heat then being transferred to produce hot air for drying inside the drying chamber. Fig. 1 shows the system diagram and the top view of evacuated tube. In additional, Fig. 2 shows the evacuated tubes and the drying chamber from short distance.

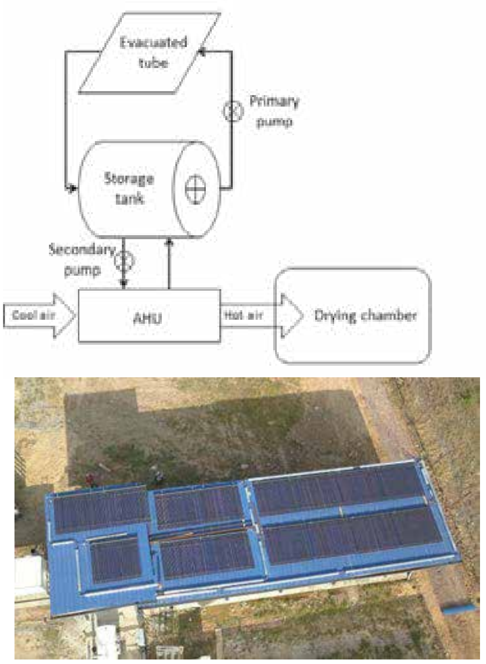

Fig. 1: System diagram (top) and top view of evacuated tube (bottom)

Fig. 2: Evacuated tube (left) and the drying chamber (right) from short distance.

A total of 175.00 kg fresh kenaf fibre divided into 35 parts with 5.00 kg each and hooked inside drying chamber. All data was recorded starting from 1015 until 1530 every 15 minutes and gathered using a combination of Graphtec GL820 data logger system and portable sensor for validation. Data collected focusing on drying chamber data (inlet temperature T_i, outlet temperature T_o, inlet relative humidity RH_i and outlet relative humidity RH_o), ambient data (irradiance intensity S, temperature T_a and relative humidity RH_a) and fibre data (weight w). Few constant values also determine such as inlet area A_i, outlet area A_o, inlet velocity v_i and outlet velocity v_o.

B. Energy Analysis

The energy release for drying fibre inside the drying chamber can be estimated by considering the different temperature between inlet and outlet of the chamber and calculated using (1) and (2).

$$Q = \dot{m}C\Delta T \tag{1}$$

$$\dot{m} = \rho A v \tag{2}$$

Where $\dot{m}$ = mass flow rate (kg/s), ρ = air density (kg/m^3), A = area (m^2), v = air velocity (m/s), C = air specific heat (J/kg K) and $\Delta T = T_i - T_o$ = inlet temperature – outlet temperature (°C).

C. Exergy Analysis

Exergy analysis can be considered as performance indication of drying system. The analysis is crucial for system improvement in many aspects [13,14]. Using the first law of thermodynamic, exergy can be calculated using (3) [15].

$$Ex = \dot{m}C\left[(T - T_a) - T_a \ln\frac{T}{T_a}\right] \tag{3}$$

From (3), inflow exergy calculates using (4)

$$Ex_{in} = \dot{m}C\left[(T_i - T_a) - T_a \ln\frac{T_i}{T_a}\right] \tag{4}$$

Where $\dot{m} = \rho A v$, $\dot{m}$ = mass flow rate (kg/s), ρ = air density (kg/m^3), A = inlet (nozzle) area (m^2), v = air velocity (m/s), C = air specific heat (J/kg K), T_i = inlet (nozzle) temperature (°C) and T_a = ambient temperature (°C). Outflow exergy calculate using (5).

$$Ex_{out} = \dot{m}C\left[(T_o - T_a) - T_a \ln\frac{T_o}{T_a}\right] \tag{5}$$

Where A = outlet area (m^2) and T_o = outlet temperature (°C). Exergy lost is different between Ex_{in} and Ex_{out} shows in (6).

$$Ex_{lost} = Ex_{in} - Ex_{out} \tag{6}$$

Ex_{in}, Ex_{out} and Ex_{lost} related each other and follow the same pattern [14] however the variation of these exergies contributed by daily irradiance intensity S [16]. Exergy efficiency μ_{Ex} also can be determined using (7)

$$\mu_{Ex} = \frac{Ex_{out}}{Ex_{in}} \tag{7}$$

D. Weight Analysis

Weight analysis was done by measuring weight w of fibre, then determined the extraction of accumulated water removed w_{awr}, current water removed w_{cwr} and its percentage; and moisture extraction rate MER as follows:

$w_{awr} = w_i - w$, where w_i= intial weight (kg)

$w_{cwr} = w_n - w_{n-1}$ (kg)

w_{cwr} percentage = $\frac{w_c}{w_i} \times 100$ (%)

$MER = \frac{\Sigma(w_{awr})}{t}$ (kg/hr), where t = drying time (hr)

E. Moisture Content

Moisture content MC can be define as wet basis w.b and dry basis d.b. Moisture content can be accurately determined by identifying the dry sample weight with 0 % MC. The sample of fibre dried inside oven and set at certain temperature and period until the weight is consistent [10,17]. This experiment will calculate MC w.b using (8).

$$MC\ w.b = 100 - \left[\left(\frac{initial\ w - final\ w}{initial\ w}\right) X100\right], (\%) \qquad (8)$$

Initial MC is 100 % because of the soaking during retting process. Moisture content will be recorded from left, center and right samples of kenaf fibre positioned inside the chamber.

III. Result and Discussion

The average values for S, T_a and RH_a are 881.4 W/m^2, 33.7 ºC and 57.3 % respectively. For drying chamber data, average T_i, T_o, RH_i and RH_o are 52.8 ºC, 46.3 ºC, 29.2 % and 39.4 % respectively. Overall ambient and drying chamber measured data are shown in Fig. 3. Normally T_i is the highest followed by T_o and T_a. Heat was absorbed by the fibre during drying process inside the chamber allowing the heat reduction at the outlet point. Compared with relative humidity, the lowest recorded at RH_i followed by RH_o then RH_a. Dry air with low humidity needed for the drying process, then it increased due to moisture extracted from the fibre at the outlet point.

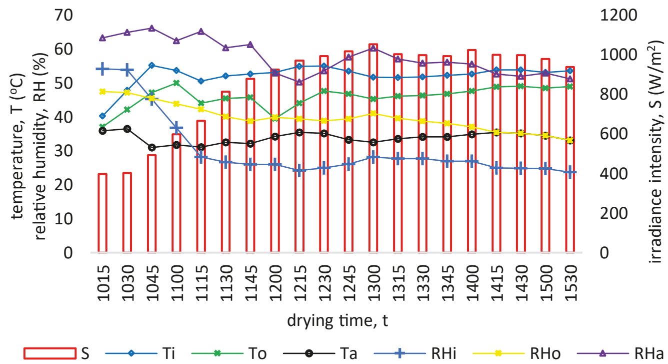

Fig. 3: Value for irradiance intensity S, temperature T and relative humidity RH of drying chamber and ambient data.

The heater is operated automatically between 70 – 80 ºC. The system is capable to increase storage tank temperature at 0.5 ºC/min and during drying process the temperature decreases at the same rate then stabilized around 60 ºC. Fig. 4 shows Q and S value over time.

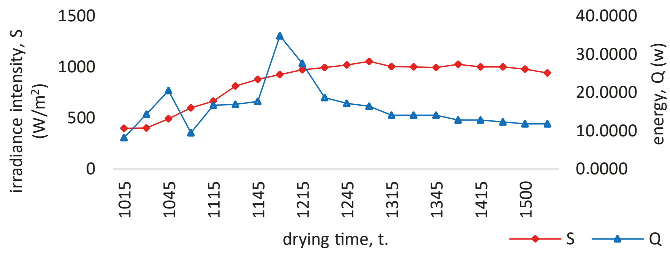

Fig. 4: Irradiance intensity S and energy Q over time.

Constant value for inflow exergy was determined: air density ρ = 1.109 kg/m^3, inlet (nozzle) area A = 0.443 m^2, air velocity v = 5.3 m/s and air specific heat C = 1.005 J/(kg K). For out flow: outlet area A = 0.900 m^2 and air velocity v = 2.4 m/s. The Ex_{in}, Ex_{out} and Ex_{lost} pattern related to Q are as shown in Fig. 5. The Ex_{in} and Ex_{out} shows the similar pattern, however Ex_{lost} is moved opposite direction with Ex_{in} and Ex_{out}. Minimum, average and maximum values of μ_{Ex} are 7.11 %, 45.05 % and 68.49 % respectively.

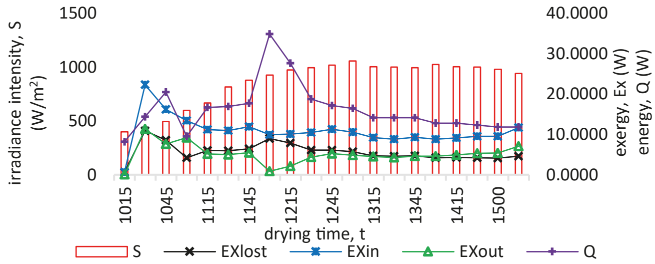

Fig. 5: Values for S, Q and Ex over drying time

After 5 hours and 15 minutes of drying time, final weight w_f is 64.40 kg. Total water removed from the fibre w_{awr} is 110.60 kg, which is equivalent to 63.2 %. The highest percentage of water being removed at the first 15 minutes is 22 % with w_{cwr} equivalent to 38.50 kg. Followed by 6.4 % at the second 15 minutes interval with w_{cwr} value of 11.20 kg. Other significant data can be observed is the relationship between w and S. Both data moved in an opposite trend over drying time. Irradiance intensity, S from the sun was used to supply heat energy for drying inside the chamber. Continuous heat supply will contribute to the reduction of w, as shown in Fig. 6. Result values of MC from three represented group are shown in Table 1 and plotted in Fig. 7.

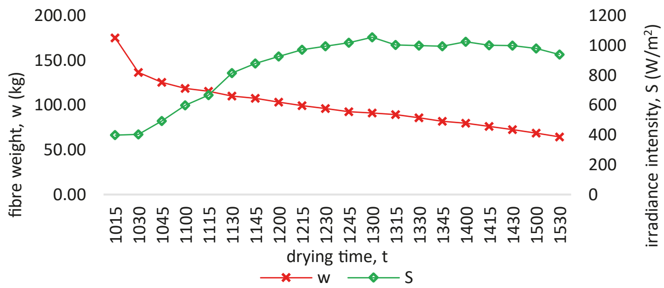

Fig. 6: Relationship between w and S over drying time.

Table 1: Result for moisture content MC wet basis in drying chamber

Sample	initial weight	final weight	initial MC	final MC
Left	5.00 kg	2.26 kg	100.0 %	45.2 %
Center	5.00 kg	1.54 kg	100.0 %	30.8 %
Right	5.00 kg	1.72 kg	100.0 %	34.4 %
Average	5.00 kg	1.84 kg	100.0 %	36.8 %

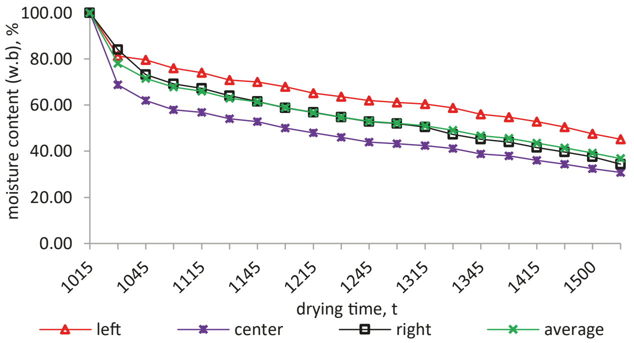

Fig. 7: Moisture content of left, center and right samples.

The variation in results between the samples impacted by three main factors which are quality of fibre, chamber orientation and hot airflow distribution inside the chamber. Low quality of fibre needs more energy and difficult to dry. This greenhouse chamber also depends on direct sunlight for drying. The fibre that oriented to the East probably experienced higher drying rate in the morning compared with the others. Forced convection inside the chamber was the most dominant factor. Hot airflow can be investigated through computer simulation and validated against experimental data.

Moisture extraction rate MER indicates the capability of the dryer to remove water from fibre in a certain period. Unit for MER is kg/hr. In this experiment, 110.60 kg water was removed within 5.25 hours with the value of MER of 21.07 kg/hr.

IV. Conclusion

Energy inside drying chamber was calculated and exergy analysis for drying chamber was performed. Similar pattern of Ex_{in} and Ex_{out} were observed over drying time. A significant relationship between w and S also detected. Within 5.25 hours of drying time, 63.2 % of water was removed from the fibre and MER value is 21.07 kg/hr. The minimum, maximum and average of moisture content w.b calculated from the sample are 30.8 %, 36.8 % and 45.2 % respectively. This work should be continued by determining component and system efficiency, weight reduction by referring to the wet or dry basis and specific moisture extraction rate SMER.

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