Solar-biomass drying system for para rubber sheet

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Abstract

Solar-biomass drying system is designed and constructed to dry 100 para rubber sheets having 135.6 kg total weight. The flat plate solar collector with area of 48 m^2 is used to provide heat for drying system from 9:00 to 17:00. After 17:00 to 9:00, firewood combustion in the biomass burner is employed to supply heat. The dimensions of the biomass burner are 1.0 × 1.0 × 1.2 m. Experimental results showed that drying with solar and biomass takes 53 hours and the final moisture content of para rubber sheet was quite constant at 1.2%db after 39 hours drying. The average drying temperature was 48.2 ^{O}C and the drying rate was 0.3 kg-water evaporated/hour. Additionally, the comparison among different drying techniques like sun exposure, smoked type and solar-biomass in terms of drying quality, cost per dried sheet and total drying time are presented. It can be concluded that para rubber sheet dried by using solar-biomass hybrid system yields the best quality, low cost per dried sheet and short drying time.

Keywords: *Solar energy, biomass, hybrid drying system, dryer efficiency, drying quality*

1. Introduction

Para rubber is one of Thailand's major crops, hence important to the country's economy. But the production process still has some problems concerning with quality, leading to lower sale prices, especially with moisture content above 3%. About 90% of the para rubber comes from small farmers plantation. Generally, the methods used to dry the rubber sheets are the shade, sun exposure, smoke, steam and hot air. To select the method, it is depends on the production and market requirement of the rubber sheet [1,2].

Single day sun exposure followed by 4 to 6 days (depending upon season) indoor drying method is used mostly in production of para rubber sheets. Solar dryer technology is one of the methods that conserve energy and easy to construct. It can be divided into two types namely dome and triangle [3]. Several researches have been done for para rubber sheet drying so far. Palavach [4] developed the solar dryer with an area of 12.5 m^2 where average drying temperature was 41.9^{O}C. The texture of dried para rubber sheet was more transparent than the one from sun exposure drying. It was found that the proper drying temperature, ranges from 40 to 60^{O}C. Pongsak et al. [5] found that the temperature in the solar drying chamber depends on ambient temperature, moreover temperature in the drying chamber for smoked type ranges from 60 to 70^{O}C. Natthaphon et al. [6] utilizes solar energy in drying of natural rubber and evaluated the system performance. The feasibility of heat dumping and the conformation of the collector array were taken into consideration. A simplified sizing process for estimation of collector area required is also developed.

Suttisak et al. [7] found that a non-uniform flow and large temperature variations in a natural rubber smoking-room result in a wasteful use of energy. Flow uniformity and temperature variation can be improved by using a computational fluid dynamics (CFD) simulation. The effects of the size, position and number of gas supply tubes and ventilating caps at the inlets and the outlets of the smoking-room were examined. The optimal rubber smoking-room size of 2.6 m × 6.2 m ×3.6 m includes 154. 50 mm diameter hot gas contribution ducts and four 0.25×0.25 m and four 0.25×0.20 m ventilating lids. The average monitoring temperature of 54 measuring positions was 62.1^{O}C. This prototype could reduce the temperature variation from the original room prototype, i.e., from 15 to 5.5^{O}C. The heat input of an appropriate room was adjusted to obtain a suitable temperature (60^{O}C) for the smoking procedure. It was found that an appropriate heat contribution at this temperature is 11 kW. At this rate, the temperature variation is 5.3^{O}C. This developed prototype should help the rubber smoking cooperatives to accomplish at least 31.25% saving in energy. Sulkiplee et al.[8] studied and investigated to compare the drying temperature in a general rubber room and rubber sheet room with a combination of solar energy and biomass. The results from the test in the drying rooms with drying time of 72 hours shows that the temperature in a drying tube, fuel consumption and fuel consumption rate were 49.64 ± 0.09^{O}C, 1,435 kg and 20 kg/hr, respectively. Thawatchai et al. [9] presented rubber sheet drying house with hybrid energy of solar and biomass which was designed to collect biomass combustive heat and under roof was designed for solar energy collecting. The study found that the average temperature in the rubber sheet drying house, amount of biomass-fuel consumption and biomass-fuel consumption ratio were about 53.55 ± 0.09 ^{O}C, 680 kg and 10 kg/hr, respectively. Songkhla Rubber Research Center [10] built the rubber dryer system. It was made of steel frame with a dimension of 2.00 m x 2.50 m. x 3 m. and the roof lined with zinc, and painted black to absorb the heat from the sun with protection from light and ultraviolet (UV) which can incident on surface of the raw rubber sheets. Solar panel which will receive heat from the sun is made of plastic corrugated sheet with area of 63 m^2. The bottom of the system is covered with soil, sand and rock, with thickness of 10 cm and having slope of 15° for the heat storage. Drying temperature ranging from 49 to 52^{o}C is higher than outside temperature of 36℃. Rubber can be baked dry within 3-4 days making raw rubber sheets with moisture content less than 1%.

From the previous works, we found that many researchers studied para rubber sheet drying using different methods such as smoked rubber, solar assistance and solar-biomass hybridization. Most researches of para rubber sheet drying emphasize on use of solar energy where accumulated heat in drying chamber is used. In the present study, flat plate solar collector is used for providing heat to dry para rubber sheet in the drying chamber. However, solar energy being unavailable during night times can only be used during day time and heat required is provided through burning of biomass for drying para rubber sheet during night time to reduce drying time and obtain good quality.

2. Theory of drying

Drying material or product and its moisture content are the most important things to be considered. Moisture content of the product is the volume of water contained in the material when compared to the mass of wet or dry material.

The unit of moisture is based on dry and wet basis which can be expressed as

Percentage of moisture dry, % $$M_d = \frac{M_w}{1-M_w} \times 100 \quad (1)$$

Percentage of moisture wet, % $$M_w = \frac{M_d}{1+M_d} \times 100 \quad (2)$$

Heat provided by solar collector can be calculated from the relationship between heat transfer coefficient of the area absorbing solar energy and the temperature difference between outside and inside of the solar collector.

$$Q = UA\Delta T \quad (3)$$

where Q is Heat transfer rate, W
U is Heat transfer coefficient, $w / m^2 °c$
A is Total absorber area, m^2
ΔT is Temperature difference between the outside and inside, °c

Heat used for drying can be obtained by the following equation.

$$Q = \frac{(h_f - h_i)}{3600} m_a \tag{4}$$

Where Q is Total heat transfer rate, kW
h_f is Enthalpy of heating air at drying temperature, kJ / kg
h_i is Enthalpy of ambient air, kJ / kg
m_a is Mass flow rate of heating air, kg / s

Overall system efficiency is defined as ratio of the amount of heat to vaporize water to input solar energy as represented in equation (6).

$$\eta = \frac{h_{fg} \times m_w}{I_t} \times 100 \tag{5}$$

where η = Overall system efficiency, %
m_w = the amount of vaporized water, kg
h_{fg} = latent heat of vaporization, kJ/kg
I_t = solar radiation intensity, W/m^2

The efficiency of biomass burner can be defined as the ratio of the amount of heat to vaporize water to heat provided by biomass burning.

$$\eta_t = \frac{h_{fg} m_w}{m_f LHV} \times 100 \tag{6}$$

where η_t = Efficiency of biomass burner, %
m_f = Mass of fuel used for drying, kg
LHV = Low Heating Value, kJ/kg

3. Solar and biomass hybrid drying system

3.1 System components

Figure 1 and 2 shows the overall system which consists of flat plate solar collector with width x length of 600 x 800 cm. Main structure is made of steel. The top of solar collector is covered with transparent glass with thickness of 50 cm and the bottom is concrete material with the thickness of 10 cm which is painted in non reflected black and endurable to heat. Biomass burner is designed to be rectangular and curved shape on the top with width x length x high of 100 x120x 100 cm. Drying room has width x length x height of 500 x 800 x 200 cm. All the four walls and ceiling of drying room are insulated in 3 layers. The outer is zinc sheet with thickness of 5.5 cm. The middle layer is made from foam with thickness of 2.54 cm. The ceiling is made of corrugated zinc with width x length of 62 x 186 cm. The ventilator is fixed at the hole of the ceiling with diameter of 2.54 cm in a square shape with width x length of 30 x 30 cm. Within the drying room, three heat pipes with the diameter of 8 inches each and thickness of 4 mm are connected with the burner. Equipment used for measuring different parameters are thermocouple type K, mass flow meter, digital balance, moisture content meter, data recorder, wet bulb and dry bulb temperature thermometer.

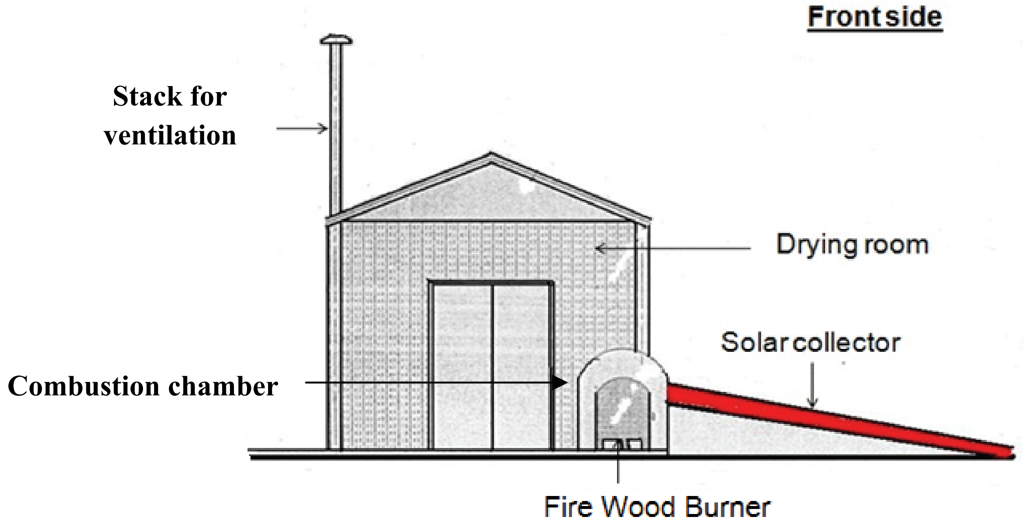


Figure 1 Schematic Diagram of Solar and Biomass Hybrid Drying System

3.2 System operation

There are two steps of system operation: preparation of para rubber sheet and drying process.

3.3 Preparation of para rubber sheet

Steps for preparation of para rubber sheet before drying comprise on;

1. Liquid para rubber collecting.
2. Liquid para rubber filltration to remove the contamination from liquid rubber.
3. Mixing liquid para rubber with water at ratio of 3:2.
4. Mixing 15% concentrated liquid para rubber (volume 5 liter) with 2-2.5 % concentrated formic acid (volume 300 ml).
5. Pressing mixture by external force or machine to form para rubber to be para rubber sheet.
6. Cleaning para rubber sheet with water.

3.4 Drying process of para rubber sheet with solar and biomass hybrid system

One hundred para rubber sheets with a total weight of 135.6kg are brought in drying room, which uses heat from a 48 m^2 flat plate collector. Drying process will continue from 9:00 -17:00 with solar energy from collector and with biomass based heat for the rest of the period. The solar and biomass hybrid system developed is shown in Figure 2.

Figure 2 Experimental solar-biomass hybrid drying system for para rubber sheet.

4. Results and discussions

Temperature profile

Figure 3 shows relationship between solar radiation and heat per weight of rubber sheet from 9:00 am to 4:00 pm. The data was collected in 20 minutes intervals. The results show that, in the first period of drying, solar radiation and the amount of heat per weight of rubber sheet are low. At 9:00 am, solar radiation and the amount of heat per weight of rubber sheet are 381 W/m^2 and 0.8 kJ/kg respectively. The solar radiation and the amount of heat per weight of rubber sheet continue to increase until 1:00 pm and the maximum solar radiation and the amount of heat per weight of rubber sheet obtained are 937 W/m^2 and 2.57 kJ/kg respectively. After that, the solar radiation and the amount of heat per weight of rubber sheet decreases gradually to 362 W/m^2 and 0.5 kJ/kg respectively at 4:00 pm.

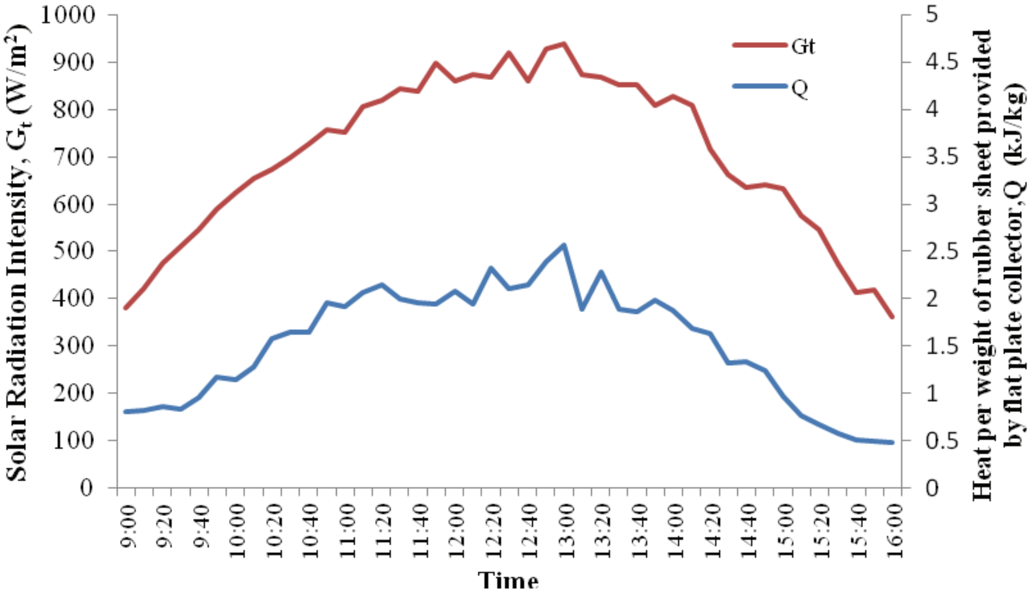


Figure 3 Relationship between solar radiation and heat per weight of rubber sheet

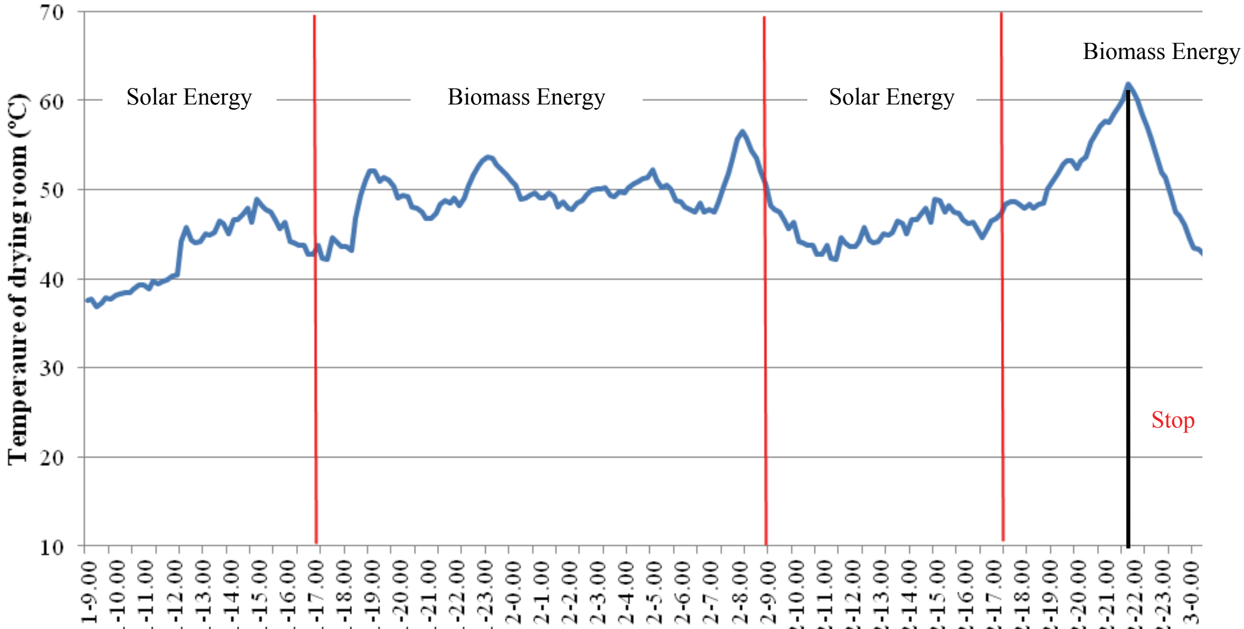


Figure 4 Relationship between drying chamber temperature using solar collector and biomass

From Figure 4, in the range of drying time from 9:00 am to 5:00 pm, while solar energy is used drying room temperature varies from 42.1 to 50.6°C, with an average temperature of 44.9°C. The drying system efficiency is 34.9%. Drying room temperature recorded is in agreement with the previous researches (40°C to 60°C) [4, 9, 11]. This range of temperature corresponds to solar radiation as appeared in Figure 3. While drying using only biomass from 5:00 pm to 9:00 am, the drying room temperature varies from 46.5 to 61.8 °C, with an average of 52.7 °C.

Para wood biomass having 7 cm diameter and 1 m length is used as fuel. The weight of biomass required is 20 kg per batch to maintain drying temperature within the 60°C limit.

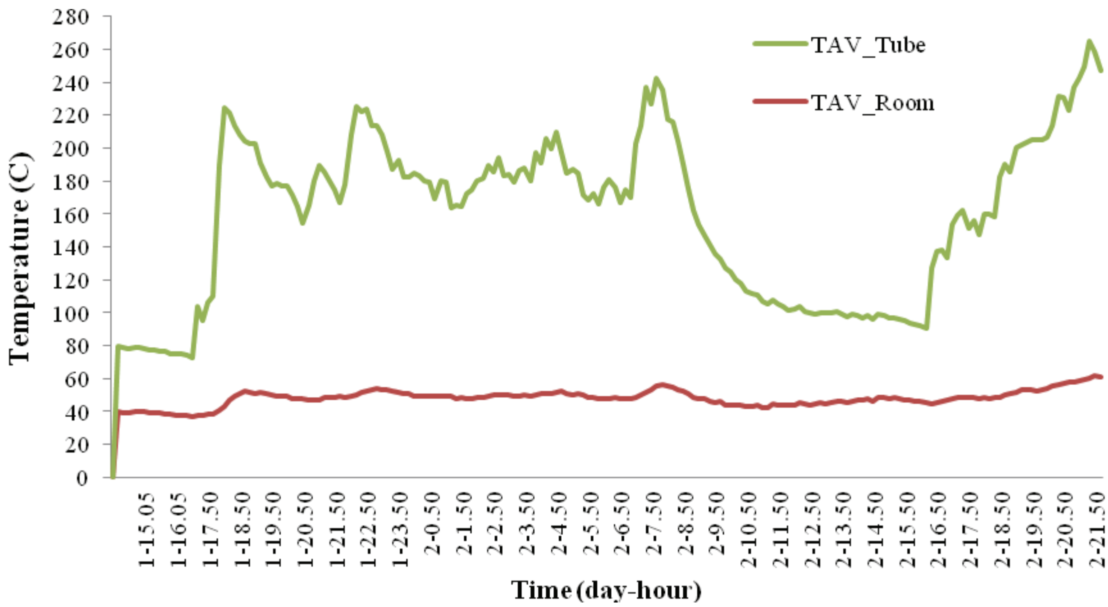


Figure 5 Temperature profile of drying chamber and heat pipe

Figure 5 shows temperature profile of drying chamber (TAV_Room) and heat pipe (TAV_Tube). It can be seen that from 9:00 am to 5:00 pm, biomass is only used as energy backup in early morning and late evening. That means drying process can be continued using solar thermal from collector. From 5:00 pm to 9:00 am heat provided by biomass is used for para rubber sheet drying, the temperature in the drying room is maintained between 45-60°C. Additionally, the efficiency of biomass burner is 1.19%. Due to the lower moisture content the amount of heat from biomass is higher. As appeared in Figure 5, the temperature in the heat pipe from biomass burner is higher than that in the drying room. It is found that the temperature in the heat pipe coming from biomass burner can be maintained in the range of 80 to 100°C. The decrease in the temperature of biomass burner can yield higher efficiency.

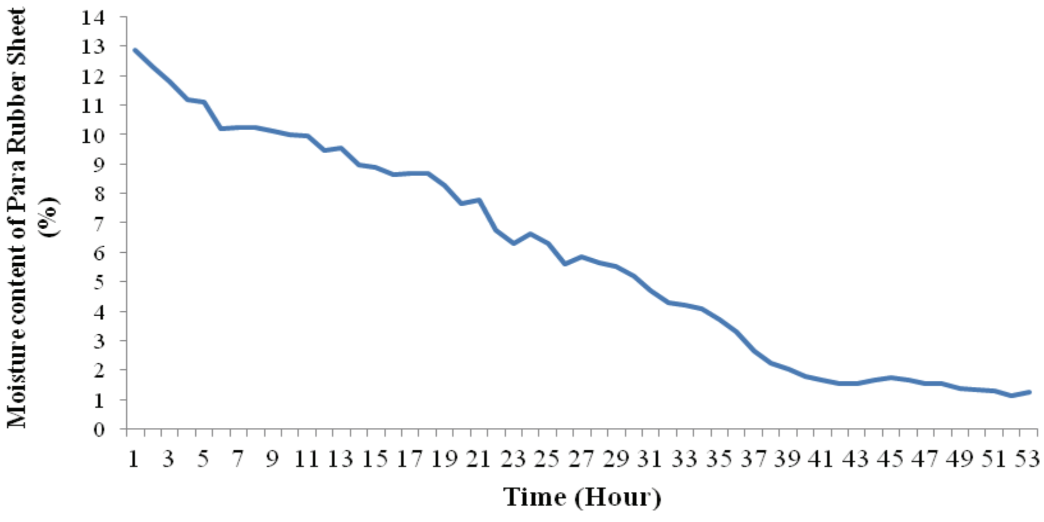
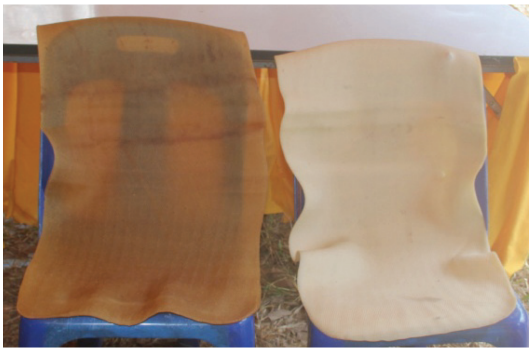


Figure 6 Drying Curve of para rubber sheet

Figure 6 shows the decrease of moisture content for para rubber sheet while drying with the solar thermal and biomass. In the first drying period, para rubber sheet contains high moisture content. The moisture content of para rubber sheet decreases by the time and becomes almost constant after 39 hours. The final moisture content of dried para rubber sheet is 1.2 % db with average drying rate of 0.3kg-water evap/hr. It can be concluded that the drying system efficiency is 67.14% and the percentage of moisture removed from para rubber sheet is 11.6. Figure 7 shows the comparison of para rubber sheet before and after drying using solar thermal and biomass hybrid process. Drying with solar energy can reduce the drying time when compared with other drying methods resulting from hot air circulation within the drying room. Study of Wasun et al. [12] shows that the high heating air velocity results in faster moisture releasing from para rubber sheet when compared to the low heating air velocity, resulting in shorter drying process.



After drying (a) Before drying (b)

Figure 7 Comparison of para rubber sheet before and after drying using solar thermal and biomass hybrid process

Table 1 shows the comparison of dried rubber sheet quality using three different methods, sun exposure, smoked type and solar-biomass hybrid process.

Table 1 Drying quality of rubber sheet with different methods

Drying method		Thickness (mm)	Moisture (%)	Weight per sheet (kg/sheet)	Size (cm)	Color	Drying time (hour)	Class
Sun exposure		< 4	< 4.5	< 1.5	38-46×89-90	Opaque	63-90	4
Smoked type		<4	<3	<1.3	38-46×89-90	Yellow	72	3
Solar and biomass		<3	1.2	1.19	38-46×89-90	Transparent yellow	53	1
Standard detail	Office of Rubber Replanting Aid Fund							
	Class 1	<3	<1.5	0.8 - 1.2	38-46×89-90	Yellow	-	
	Class 2	<4	<2	1.0 - 1.2	38-46×89-90	Yellow	-	
	Class 3	<4	<3	< 1.3	38-46×89-90	Yellow	-	
	Class 4	<4	<4.5	<1.5	38-46×89-90	Opaque	-	

Table 1 indicates that solar-biomass hybrid drying process yields the best class (class 1) of drying quality for acceptability in para rubber sheet market and utilizes the shortest drying time when compared with the sun exposure and smoked type techniques.

Drying cost per a dried para rubber sheet

The results show that the drying cost for smoked method is 63.2 THB per kilogram while dried para rubber sheet which obtained from solar-biomass hybrid process has value add about 16.3 THB per kilogram. (Referring cost from office of Rubber Replanting Aid Fund at 6th March 2015) Based on the cost of firewood used as biomass (1 THB per kilogram), the cost of firewood per dried para rubber sheet using solar-biomass hybrid drying system comes out to be 1 THB while it is 3 THB for smoked drying method. It can be seen that solar-biomass hybrid system developed, reduces the biomass fuel cost up to 66.7%. Labor cost (based on 300 THB per person per day), for solar-biomass hybrid drying system is 1.50 THB per a dried para rubber sheet, while it is 2.40 THB per a dried para rubber sheet for smoked drying method. It shows that solar-biomass hybrid drying system can reduce the labor cost up to 37.5%. (Referring cost from office of Rubber Replanting Aid Fund at 6th March 2015)

Drying time

Drying with solar-biomass hybrid system takes 53 hours while smoked drying method needs 72 hrs. The hybrid drying system thus saves 26.4%.drying time.

5. Conclusions

In this research, the solar-biomass hybrid dryer was designed and fabricated for drying 100 para rubber sheets. The hot air from flat plate solar collector with area of 48 m^2 is utilized to provide heat for the drying process from 9:00 am to 5:00 pm and a biomass burner which used para firewood is utilized for drying process from 5:00 pm to 9:00 am. Initial moisture content of para rubber sheet was 12.8 %db and was decreased by the dryer to a lower value of 1.2%db. The average drying rate is 0.3 kg-water evap/hr. The drying system efficiency is 67.14%. From the comparison of different drying methods (solar-biomass hybrid, sun exposure and smoked type) in terms of quality, cost per dried para rubber sheet and drying time, it can be concluded that solar-biomass hybrid drying process yields the best class of drying quality(class 1) for acceptance in para rubber market and spends the shortest drying time. Further solar-biomass hybrid drying system can reduce the labor cost up to 37.5% and drying time up to 26.4% when compared with smoked type and open-sun dry method.

References

[1] Office of Agricultural Economics, (2011) Agricultural Statistic of Thailand 2011, Ministry of agriculture and cooperatives, 402, 79.

[2] Nakhon Si Thammarat Provincial Energy Office, (2006) Report of local energy planning, Ministry of Energy, 1, 9.

[3] Prakash, O. and Kumar, A. (2014).Solar greenhouse drying : A review, Renewable amd sustainable Energy Reviews. 29, 905-910.

[4] Palavach wongyos,(2012). Development of solar drying for Para rubber sheet. Master thesis. Ratchabaht Ubonratchathanee.

[5] Pongsak Yoomun, Sirichai Thepa and Pichai namprakay,(2006).Comparison beteween solar drying and smoking house of para rubber sheet. The conference of Energy and Material.Thailand.

[6] Natthaphon Roonprasang, Taveewat Suparos and Phira Vijasika, (2009) Rubber Drying System by Using Solar Energy and Thermal Energy Storage System, Conferences of Kamphaeng Sean Campus,6th Kasetsart University,630-638.

[7] Suttisak Kaewnok and Sirichai Thepa, (2007) A Modeling of the solar-assisted for rubber smoked sheets (rss) system, Engineering Journal of Siam University, 2, 51-55.

[8] Sulkiplee Kasor, Pornsak Somprasong, Suwit Phethuayluk, Pornpana Buaphet and Thawatchai Tepnual, (2009) A comparison of temperature within local rubber sheet house and drying rubber sheet house with hybrid energy of solar and biomass.Conferences of Thaksin University, 19th, Songkha, Thailand.

[9] Thawatchai Tepnual, Suwit Phethuayluk, Sukkiplee Kasor, Pornsak Somprasong and Pornpana Buaphet (2010). Energy consumption of rubber sheet drying house with hybrid energy of solar and biomass. Thaksin Journal. 12 (3),121-128.

[10] Songkhla Rubber Research Center, (2008) Solar drying of rubber sheet, Department of Agricultural, 153.

[11] Sulkiplee Kasor, Perapong Tekasakul and Thawatchai Tepnual. (2012).Temperatures distribution in a drying rubber sheet house with hybrid energy of solar and biomass using computational fluid dynamics in state of without rubber sheet. Journal of Taksin University.3,277-286.

[12] Wasun Jeentada, Pornprasit Kongboon, Sittipom Boonyanuwat and Chalem Sirirak, (2014). Thin-layer drying models for para rubber sheet. KKU Engineering Journal. 41(1),99-108.