Mathematical Model of Smoking Time Temperature Effect on Ribbed Smoked Sheets Quality

Rifah Ediati, and Jajang

Abstract— The quality of Ribbed Smoked Sheets (RSS) primarily based on color, dryness, and the presence or absence of fungus and bubbles. This quality is strongly influenced by the drying and fumigation process namely smoking process. Smoking that is held in high temperature long time will result scorched dark brown sheets, whereas if the temperature is too low or slow drying rate would resulted in less mature sheets and growth of fungus. Therefore need to find the time and temperature for optimum quality of sheets. Enhance, unmonitored heat and mass transfer during smoking process lead to high losses of energy balance. This research aims to generate simple empirical mathematical model describing the effect of smoking time and temperature to RSS quality of color, water content, fungus and bubbles. The second goal of study was to analyze energy balance during smoking process. Experimental study was conducted by measuring temperature, residence time and quality parameters of 16 sheets sample in smoking rooms. Data for energy consumption balance such as mass of fuel wood, mass of sheets being smoked, construction temperature, ambient temperature and relative humidity were taken directly along the smoking process. It was found that mathematical model correlating smoking temperature and time with color is Color = -169 - 0.184 $T4$ - 0.193 $T3$ - 0.160 0.405 $T1$ + $T2$ + 0.388 $t1$ +3.11 $t2$ + 3.92$t3$ + 0.215 $t4$ with R square 50.8% and with moisture is Moisture = -1.40-0.00123 $T4$ + 0.00032 $T3$ + 0.00260 $T2$ - 0.00292 $T1$ - 0.0105 $t1$ + 0.0290 $t2$ + 0.0452 $t3$ + 0.00061 $t4$ with R square of 49.9%. Smoking room energy analysis found useful energy was 27.8%. The energy stored in the material construction 7.3%. Lost of energy in conversion of wood combustion, ventilation and others were 16.6%. The energy flowed out through the contact of material construction with the ambient air was found to be the highest contribution to energy losses, it reached 48.3%.

Keywords— RSS quality, temperature, time, smoking room, energy

I. INTRODUCTION

INDONESIA is the second largest country of rubber exporter after Thailand. Today, Indonesian rubber export continues

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to increase. The exports data showed an increase from 234,966,062,988 kg equal to U.S. $ 48,665,452,518 in 1999 to 310,302,233,454 kg (32%), or worth U.S. $ 103,158,895,291 (112%) in the year 2007 [1] Total Indonesian rubber production in 2004 reached 2.06 million tons. Whereas 2005 increased to 2.128 million tons. A major destination of Indonesian rubber exports is China. In 2004 China imported 207 thousand tons of rubber from Indonesia [2]. Rubber production of PTP Nusantara IX (Persero), where study was held, in 2005 was 21,603,000 kg increased to 22,897,084 kg in 2006 (6%).

Ribbed smoked sheets are used in various industries due to their variety in the requirements on cleanliness and tear strength of the sheets. There are five major grades: RSS 1 to RSS 5. According to the International Standards of Quality and Packing for Natural Rubber Grades [3], the quality of RSS is based on several factors such as presence or absence of fungus, spots due to oxidation, dryness, cleanliness, strength, color, and defects (stains, dirt, foreign objects, and air bubbles).

The difference in the grades is resulted by the preparation of the coagulated field latex during the production of the non-smoked sheets and greatly influenced by the smoking process. The sheets are selected and smoked at a controlled timing and temperature window to ensure that they are properly smoked without causing negative impact on the rubber properties. However, the smoking process done here in PTP Nusantara IX Rubber Manufacturer and also throughout Indonesia are still very conventional. Smoking is still done in rooms without appropriate temperature control system [4]. Two main problems are exist. First is the large variation of the temperature, between 40°C to 60°C (as large as 20 °C). The previous study [5] reported variation of temperature can be as great as 15 °C. The problem arises because of discontinuity of fuel wood feeding as its heat source. Discontinues feeding is caused by no good monitoring and there is no temperature alert (whether it is lower or higher than temperature adjusted) which can remind the operator to add fire wood when the temperature drop and vice versa.

Unstable temperature during smoking time influenced in large variation of rubber quality parameter. Smoking of too long time and too high temperature can caused sheets burned so resulted in dark brown sheets, whereas the smoking temperature of too low and less long time can lead sheets less mature and grow fungus. Since RSS grades still depend heavily on visual inspection [6], visual properties such as

color, dryness, fungus and bubbles are very important to be first evaluated during all RSS production include smoking process. Right temperature and curing time will produce high-quality sheets. Then, uncontrolled heat and mass transfer during smoking also lead to second main problem that is fuel wood energy waste.

Based on the background of those problems, this study has two main goals. First to find mathematical model describing the relationship between smoking time and temperature with RSS quality parameter of color, moisture, fungus and bubbles. Second, to analyze energy balance of the smoking room based on fuel wood combustion and heat and mass transfer during sheets evaporating process.

II. MATERIALS AND METHODS

A. Materials and tools

Materials used were raw sheets, dry sheets, rubber smoking room, fuel wood. The tools used were infrared thermometer, room thermometer, bomb calorimeter for measure fuel wood heat value, oven for moisture measurement, and Munshell chart for color evaluation.

B. Methods

Research is experimentally conducted in Banyumas Krumput Rubber Manufacturer and Plantation of PTP Nusantara IX, Indonesia from October to November 2009. Variables measured are the temperature and residence time of sheet in each part of the smoking room and the quality of sheets of color, moisture, fungus and bubbles. Temperature is measured using infrared and room thermometer, color measured by the Munshell chart, moisture by oven method.

Smoking room can theoretically divided into four parts that are gradually different in temperature according to the distance to the heat source that is fuel wood furnace. Temperature measurements made every 1 hour for 120 hours in each smoking room. We observe 4 smoking rooms and in every room we take 4 samples for quality measurements, so we obtained 16 replications of RSS properties data. Then data of time-temperature and quality properties were analyzed to perform mathematical model and find empirical equation.

Analysis of energy balance are counted based on the energy produced by fuel wood as input energy (Eq. 1), and energy used for increasing sheets temperature and evaporating moisture from the sheets as the useful energy (Eq. 2 and Eq. 3) The rest energy lost via wall and roof, stored in the construction materials such as wall, door, ceiling and floor (Eq. 4, Eq. 5 and Eq. 6). Uncountable energy were used in evaporating moisture from fuel wood itself etc counted by different. The equations are [7]:

Input Energy, calculated from fuel wood heating value
$$Q_{in} = HV.m_v.(1-\phi) \quad (1)$$

Latent heat of vaporization of sheets moisture
$$Q_{wr} = m_{wr}.h_{fg65oC} \quad (2)$$

Sensible heat of rubber $\quad (3)$
$$Q_r = (m_r.C_{pr}.\Delta T)$$

Conduction through wall,
$$Q_k = \Sigma(k.A.\Delta T/\Delta x.\Delta t) \quad (4)$$

Radiation and Convection of Steel Door
$$Q = \Sigma(\varepsilon.\sigma.A.(T_o^4 - T_a^4).\Delta t) \quad (5)$$
$$Q = \Sigma(h.A.(T_o - T_a).\Delta t) \quad (6)$$

Heat stored in Room Structure
$$Q_s = \Sigma(m_s.C_{ps}.\Delta T) \quad (7)$$

III. RESULT AND DISCUSSION

A. Time-Temperature

The rubber smoking room dimensions are 3 m wide x 20.3 m depth x 3.5 m height. Smoking room temperature can be divided into 4 parts ranging from the highest temperature that is closest from the furnace to the lowest temperature that is furthest from the furnace. Non-smoked rubber sheets are hung on bamboo stems for drip drying before entering the smoking rooms where they are dried and cured by hot smoke produced from the furnace.

The total drying time for each batch of sheets in smoking room is about 5 days. From the observations, the sheets residence time along the smoking room space is about 108-111 hours. Sheets originally loaded on the far side (T4) from the furnace where the sheets are treated at the lowest temperature during its stay in fumigation space. In this section sheet lived as long as t1 that usually a day. After about a day of sheets residence time at T4 parts, sheets driven deeper into the T3 as long as t2. At this time, new sheets loaded in the T4 as the second input sheets. On the third day, first sheets driven to the temperature T2 space and stay here as long as t3. In this time, the third input sheets are loaded in T4 part, and so on. Later on day 4th and 5th, the first sheets reached the T1 room part during t4, and then the drying and smoking process ended.

Detail of temperature and residence time of sheets on each part of the smoking room and the properties of RSS resulted can be seen in Table I. RSS quality properties in this case are color and moisture. It is noted that the presence of fungus and bubbles were not found in the samples taken. From Table I, it can be noticed that temperature range of variation on each space are 3.49 to 6.37 C and among-space variations are as great as 20 °C. Therefore, between room I, II, III, and IV do not show different temperature trend. Sheets color were range from 3.6 to 10.7 (Munshell chart scale). Dry sheets moisture were range between 1.3% to 4.7% (g/g wet basis). It is noted that fungus and bubbles were not found on sample taken. Bubbles were found in sheets on upper layer which is closer to room roof where temperature tend to be higher due to heat stored on roof material. All sample evaluated in this study were taken from second layer. Vertically, sheets hung on bamboo on four layer.

Mathematical model based on data in Table I was created by PLS method and the gradual regression. By the gradual regression was obtained empirical equations of time

TABLE I
ROOM TEMPERATURE, RESIDENCE TIME OF RUBBER AND RUBBER QUALITY

SMOKING ROOM	SAMPLE	TEMPERATURE (ºC)				TIME (HOURS)				COLOR	MOISTURE (%wb)
		T4	T3	T2	T1	t1	t2	t3	t4		
Room 1	Test I	42.18	47.56	54.96	59.22	2092	23.08	22.67	38.00	7.21	0.02
	Test II	43.20	48.58	50.52	58.57	23.17	22.67	24.00	34.50	10.70	0.05
	Test III	41.44	45.50	56.38	59.12	22.67	23.00	23.00	23.50	5.60	0.02
	Test IV	41.42	52.00	53.42	59.94	23.00	23.00	23.00	34.00	5.00	0.01
Room 2	Test I	40.71	48.28	50.92	60.16	19.92	23.17	22.67	38.00	7.21	0.01
	Test II	42.56	52.46	51.58	57.49	23.17	22.67	23.00	37.50	5.60	0.01
	Test III	47.96	49.63	56.38	59.63	22.67	23.00	23.00	37.00	3.60	0.01
	Test IV	43.08	56.80	55.08	59.95	23.00	23.00	23.00	37.00	9.40	0.01
Room 3	Test I	42.62	48.38	54.71	60.08	19.92	23.17	22.67	37.00	5.60	0.07
	Test II	46.64	52.21	55.38	58.65	23.17	22.67	23.00	37.50	5.60	0.01
	Test III	49.79	49.79	55.52	55.29	22.67	23.00	23.00	37.00	3.60	0.02
	Test IV	44.65	47.46	53.05	53.77	23.00	24.00	22.00	37.00	5.00	0.01
Room 4	Test I	43.00	45.17	48.92	59.09	20.83	23.00	23.00	37.00	8.94	0.01
	Test II	43.29	44.46	53.00	58.22	23.00	23.00	23.00	35.50	9.40	0.01
	Test III	41.42	49.10	49.42	58.53	23.00	23.00	23.00	36.50	5.60	0.01
	Test IV	47.81	46.58	49.86	58.58	23.00	23.00	23.00	37.00	9.40	0.01
	Maximum	49.79	56.80	56.38	60.16	23.17	24.00	24.00	38.00	10.70	0,07
	Minimum	40.71	44.46	48.92	53.77	19.92	22.67	22.00	23.50	3.60	0.01
	Average	43.86	49.00	53.07	58.52	22.32	23.03	22.94	35.88	6.72	0.02
	Std Deviation	2.73	3.18	2.55	1.75	1.18	0.30	0.39	3.49	2.23	0.02
	Variance	5.46	6.37	5.11	3.49	2.37	0.61	0.78	6.97	4.46	0.03
Confidency	Lower limit	38.04	42.21	47.63	54.80	19.80	22.38	22.11	28.45	1.97	-0.02
Interval	Upper limit	49.68	55.78	58.51	62.24	24.84	23.67	23.77	43.30	11.46	0.06

temperature relationship with the quality properties of color was $Y_1 = -169 – 0.184T4 – 0.193T3 – 0.160T2 + 0.405T1 + 0.388t1 + 3.11t2 + 3.92t3 + 0.21 t4$ and empirical equation for time-temperature effect on moisture was $Y_2 = -1.40 - 0.00123T4 + 0.00032T3 + 0.00260T2 - 0.00292T1 - 0.0105t1 + 0.0290t2 + 0.0452t3 + 0.00061t4$. From the equation above, the value of R square for Y_1 (color of sheets) is 50.8 means that the model could only explain the linkages between 50.8% time-temperature aspect to color value and the R square of Y_2 (moisture of sheets) is about 49.9 means that the model only able to explain 49.9% of the time-temperature effect on moisture. With this equation we obtained the graph of observe and predicted value of each properties as in Figure 1 and Figure 2.

The value of quality RSS measured and predicted can be seen in Table II. Further, test has also been conducted on the effect of different smoking room to the sheets quality. From the ANOVA table can be concluded that there is no significant smoking room condition contribute to the quality variation of RSS. So it can be stated that the variation of sheets quality is merely caused by fluctuation and unstable smoking time-temperature in a smoking room, not by differences among room. From these results also can be a reference to conduct further research in order focused on only one smoking room with augmented sampling to obtain a more representative mathematical models, with larger R square value.
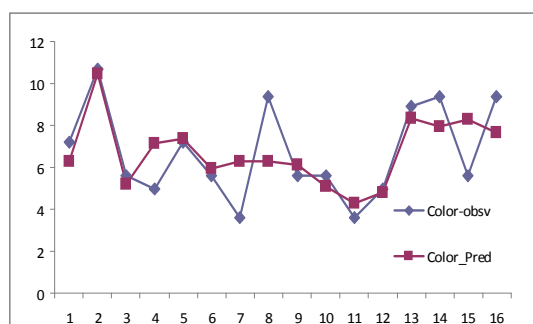

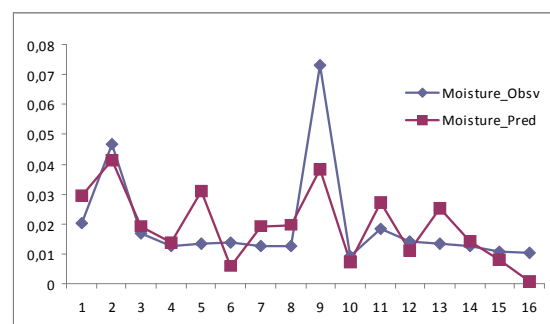Fig. 1 Effect of time-temperature on sheets color

Fig. 2 Effect of time-temperature on sheets moisture

TABLE II
OBSERVES AND PREDICTED VALUE
OF SHEETS COLOR AND MOISTURE

Color-Obsv	Color_Pred	Moisture_Obsv (%wb)	Moisture_Pred (%wb)
7,210	6,311	0,020	0,029
10,700	10,434	0,047	0,041
5,600	5,178	0,017	0,019
5,000	7,125	0,013	0,014
7,210	7,363	0,014	0,031
5,600	5,923	0,014	0,006
3,600	6,298	0,013	0,019
9,400	6,280	0,013	0,020

B. Energy Analysis

Smoking room construction are made from brick for wall, asbestos for roof, steel for door and brick for furnace. There are no isolation system. This construction contribute to energy usage optimization due to conduction, convection and radiation. Energy input is yielded from conversion of fuel wood due to its 27,667 kJ/kg heat value whereas its moisture is 23.8%wb. Result of energy calculation is shown in Fig. 3. By defining input energy as 100%, the useful energy is only 24%. The rest energy stored in the construction of walls, doors, floors and roofs is 7%. The energy loss to the surrounding through construction of walls, doors and roof is 48.3%. The rest energy is 20% due to losses in the conversion of wood energy into heat and loss by ventilation, chimneys and others. It is found that very low efficiency of energy usage happened and the largest loss contributor is material construction.
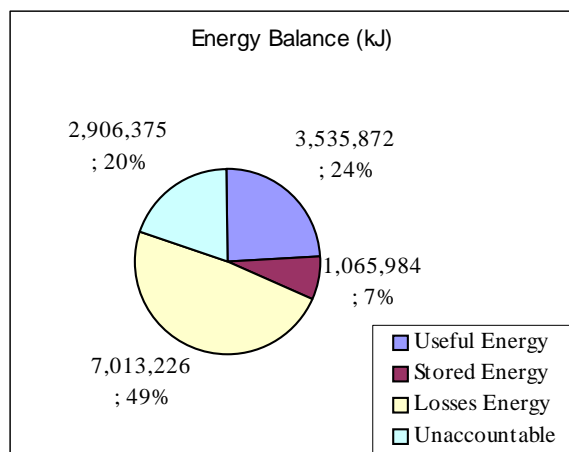

Fig. 3 Energy usage of Smoking Room System

IV. CONCLUSION

Mathematical model to describe RSS quality relationship with temperature and smoking time is Color, $Y_1 = -169 - 0.184T4 - 0.193T3 - 0.160T2 + 0.405T1 + 0.388t1 + 3.11t2 + 3.92t3 + 0.21 t4$ with R square 50.8% and Moisture, $Y_2 = -1.40 - 0.00123T4 + 0.00032T3 + 0.00260T2 - 0.00292T1 - 0.0105t1 + 0.0290t2 + 0.0452t3 + 0.00061t4$ with R square of 49.9%. So far, those empirical equation still have poor relationship. Energy balance analysis shown that smoking room operated in low energy efficiencies that only 24% of produced energy were used to evaporate moisture of rubber. Materials used in the smoking room construction contribute high loss due conductive, convective and radiation heat transfer. All these study result will be used as consideration in designing new smoking room system at second step of research.

NOMENCLATURE

A = Wall area (m^2)
HV = Heating value of rubber wood = 13,600 kJ/kg
L = Height of door (m)
Q_{in} = Input energy to the smoking room (kJ)
Q_k = Energy loss due to conduction through walls (kJ)
Q_{wr} = Latent heat of water (kJ)
Q_r = Sensible heat of rubber
Q_s = Energy stored in room stucture
T_i, T_o, T_a = Inside, outside wall surfaces and surrounding temperatures, respectively (K)
C_{pH20} = Specific heat of watter, water vapor and air, respectively.
C_{pr} = Specific heat of rubber = 1,84 kJ/kg K [6]
C_{ps} = Specific heat of room structure materials (Cps steel = 0.447 kJ/kg K, Cps brick = 0.960 kJ/kg K, Cps asbestos = 1.050 kJ/kg K, Cp floor = 1.000 kJ/kg K.
$H_{fg\,650C}$ = Latent heat of water at 65^0C
k = Thermal conductivity (W/mK)
m_r = Mass of smoked rubber (kg)
m_s = Mass of room structure (kg)
m_w = Mass of firewood (kg)
m_{wr} = Mass of water removed from rubber (kg)
T1, T2, T3, T4 = Smoking room temperature (^{o}C)
T1, t2, t3, t4 = Residence time of rubber in the 1st, 2nd, 3rd and 4th space of smoking room (hour)
t = Time (hour)
ϕ = Wall thickness (m)
$Y1$ = Color (brown color of Munsell chart scale)
$Y2$ = Moisture (%wb)

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