Energy and Exergy Analysis of Forced Convective Ribbed Smoked Sheet Drying Process

Pennung Inthararak

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Mechanical Engineering
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ชื่อวิทยานิพนธ์ การวิเคราห์พลังงานและเอกเซอร์ยีในกระบวนการรมควันยางพาราด้วย วิธีการพาความร้อนแบบบังคับ

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บทคัดย่อ

ในงานปัจจุบันได้ทำการศึกษาและวิเคระห์พลังงานและเอกเซอร์ยีของกระบวนการรมควันยางพาราด้วยวิธีการพาความร้อนแบบบังคับ โดยจะมีปริมาณยางพาราแผ่นที่ใช้ในการทดลองอยู่ที่ประมาณ 1,500 แผ่น การเตรียมการก่อนกระบวนการอบแห้งแผ่น โดยทำการบีบยางสดให้เป็นรูปสี่เหลี่ยมผืนผ้าที่มีขนาดความยาวที่ 90-100 ซม. กว้าง 40-50 ซม. และหนา 3-4 มม. หลังจากนั้นจะนำไปผึ่งในอุณหภูมิสภาพแวดล้อมเป็นเวลา 10-12 ชั่วโมง โดยที่ความชื้นเริ่มต้นของยางพาราแผ่นจะอยู่ระหว่าง 35-40% ก่อนที่จะเริ่มกระบวนการอบแห้ง โดยจะทำการทดลอง 2 ตัวแปร 1.ความเร็วของลมร้อนและ 2. ความชื้นของเชื้อเพลิง ความเร็วที่ใช้ในการทดลองนั้นจะมีค่าอยู่ที่ 12 และ 14 เมตร/วินาที และความชื้นของเชื้อเพลิงจะมีค่อยู่ระหว่าง 24-55% (ฐานแห้ง) และจะทำการบันทึกอุณหภูมิภายใน, ภายนอก, สิ่งแวดล้อมของห้องรมควันและน้ำหนักของที่ใช้ในการทดลอง ในการวิเคระห์พลังงานของการอบแห้งนั้นจะใช้ทฤษฎีตามกฎของที่ 1 ของเทอร์โมไดนามิกส์ ซึ่งผลปรากฏว่าในการทดลองทุกกรณีจะใช้เวลาทั้ง 36 ชั่วโมง ประสิทธิภาพทางความร้อนของห้องรมควันนั้นจะมีค่าประสิทธิภาพทางความร้อนอยู่ระหว่าง 12.3 – 16.9% การใช้พลังงานจำเพาะจะมีค่าอยู่ระหว่าง 13.5-16.9 เมกะจูล/กิโลกรัมของน้ำที่ระเหย การจากวิเคราะห์จะพบว่าในเงื่อนไข ความเร็วทางเข้า 12 เมตร/วินาที, ความชื้นเชื้อเพลิง 55% (ฐานแห้ง) และความเร็วทางเข้า 14 เมตร/วินาที, ความชื้นเชื้อเพลิง 55% ประสิทธิภาพทางความร้อน

สูงสุดและการใช้พลังงานจำเพาะที่ต่ำที่สุดและพิจารณาร้อยละของยางดี (ยางแผ่นรมควันชั้น 3) ทั้ง 2 เงื่อนไขมีค่าอยู่ที่ ร้อยละ 100 นอกจากนั้นเมื่อนำงานวิจัยก่อนหน้านี้มาเปรียบเทียบจะพบได้ว่าสามารถที่จะลดระยะเวลาการอบแห้งจาก 48 ชั่วโมง เหลือเพียง 36 ชั่วโมง นอกจากนั้นยังสามารถเพิ่มประสิทธิภาพทางความร้อนจากเดิมที่ 14.3% เป็น 16.7% ซึ่งพอที่จะสรุปผลได้ว่าความชื้นที่สูงของเชื้อเพลิงเหมาะสมในกระบวนการรมควันยางพาราแผ่นมากกว่าเชื้อเพลิงที่มีความชื้นต่ำ

การวิเคราะห์เอกเซอร์ยีของการอบแห้งเป็นการหาพลังงานที่สามารถใช้งานได้จริงในกระบวนการ ซึ่งจะใช้กฎข้อที่ 2 ของเทอร์โมไดนามิกส์ในการวิเคราะห์ ในการทดลองนั้นประสิทธิภาพของเอกเซอร์ยีนั้นจะมีค่าอยู่ระหว่าง 2.2-5.8% โดยเงื่อนไขความเร็วทางเข้า 12 เมตร/วินาที, ความชื้นเชื้อเพลิง 24% (ฐานแห้ง) มีค่าประสิทธิภาพของเอกเซอร์ยีสูงสุด แต่เงื่อนไขดังกล่าวนั้นมีค่าประสิทธิภาพทางความร้อนที่ต่ำที่สุด เนื่องจากการวิเคราะห์เอกเซอร์ยีของระบบนั้นจะอ้างอิงอุณหภูมิที่ทางเข้าและทางออกของห้องรมควัน โดยเงื่อนไขดังกล่าวมีอุณภูมิที่สูงที่สุดเมื่อเทียบเทียบกับเงื่อนไขอื่นๆ จึงส่งผลให้ประสิทธิภาพของเอกเซอร์ยีนั้นมีค่าสูงตามไปด้วยแต่เมื่อพิจารณาร้อยละยางดีของการทดลองนั้นจะมีค่าต่ำที่สุด (54.7%) เนื่องจากอุณภูมิที่ทางออกสูงจนเกินไป (78.0±7.5) ส่งผลให้ยางพาราแผ่นในการทดลองเกิดฟองอากาศขนาดใหญ่และมีสีคล้ำ ส่งให้ไม่เป็นไปตามมาตรฐานยางพารารมควันชั้น 3 จึงผลพอที่จะสรุปได้ว่าประสิทธิภาพเอกเซอร์ยีที่สูงที่สุดไม่เหมาะสมกับกระบวนรมควันยางพาราแผ่น

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Abstract

Present work is analysis energy and exergy of forced convective ribbed smoked sheet drying process. The capacity of smoking room is (apoximately1500 sheets). The prepare before drying process by fresh rubber sheet squeezed to thin shape. Height 90-100 cm.*width 40-50 cm. and thickness 3-4 mm. after brings to dried ambient temperature during 10-12h. The initials moister of rubber about 35-40% before starts drying process. The work is varied are velocity inlet and moisture content of fuel-wood. Velocity is varied between 12 and 14 m/s and moisture content varied between 24-55% (Dry basis). The experiments are recorded temperature (inside outside and ambient of smoking room), weight of rubber sheet sample and fuel-wood used the combustion.

The thermal analysis of drying room used to follow the first law of thermodynamic methodology. The thermal efficiency of drying all conditions between 12.3-16.7 %. The specific energy consumption between (SEC) between 13.5-16.9 MJ/kg of water evaporated. All conditions used drying time at 36 h. Considering, the experiments used wet fuel-wood (inlet velocity 12 m/s, 55% db of fuel-wood and inlet velocity 14 m/s, 53% db of fuel-wood) have the thermal efficiency are the highest and the lowest of overall specific energy consumption (SEC). Moreover, Percentage of rubber good quality have 100%. Conclude, the rubber smoking room optimize with the wet fuel-wood. Comparison between the forced convection rubber smoking room

Dejchanchaiwong et al. (2017a) same type. Results, the present work can reduce SEC from 16.4 to 13.2 MJ/kg of water evaporated and drying time

48h to 36h. Moreover, present work increased thermal efficiency from 14.3% to 16.7%.

The exergy analysis of drying room finds to availability energy of system. The overall exergy efficiency between 2.2-5.8. Considering, second ‘law efficiency is the highest (inlet velocity 12 m/s, 24% db of fuel-wood) but thermal efficiency and specific energy consumption (SEC) are the lowest. Due to second ‘law efficiency is direct variation with temperature inlet and outlet of smoking room. In condition inlet velocity 12 m/s, 24% (db) of fuel-wood have average temperature is the highest (78.0±7.5) comparison with other condition. But, percentage of good quality is the lowest (54.7%) comparison with other conditions. Because, the high temperature rubber sheet has bubbles and dark brown not follow standard of RSS 3 Conclude, second ‘law efficiency is the highest not optimize for the smoking room.

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Nomenclature

AFS	accumulated fuel-wood supply
Cp	average specific heat of the hot air, kJ/kg.K
E	total supplied energy, kJ
Ex	exergy, kJ/kg
g	gravity force, (9.8 m / s^2)
HV	heating value of the fuel-wood, (kJ/kg)
L	latent heat of vaporization, (kJ/kg)
M	moisture content, %
m	mass, kg
P	ambient pressure, KPa
s	entropy, (kj/kg.k)
SEC	specific energy consumption, kJ/kg
T	temperature, (K)
t	time, hour
u	internal energy, (kj/kg)
V	velocity, m/s
v	specific volume, m3/kg
w	weight, kg
Z	height, (m)

Greece symbols

η	efficiency, %

Nomenclature (Continued)

Subscripts

t	total
water	water
dryer	dryer
L	loss
wood	wood
e	electricity
d	dry
w	wet
dried-rubber	dried rubber
in	inlet
out	outlet
destroyed	destroyed
system	system
0	ambient
avg	average

Chapter 1

Introduction

1.1 Introduction

Natural rubber (NR) is an important agricultural product of Thailand. In 2019, Most of NR products are exported in the forms of ribbed smoked sheet (RSS), block rubber and concentrated latex. NR production has been widely preserved in the form of RSS rubber prior to production. In years 1994-1995, the Thai government supported small farmer groups to establish nearly 700 rubber cooperatives, particularly in the south of Thailand (Kalasee et al., 2013). Two models of the rubber smoking room named Model 1994 (capacity 1.5 tons) and Model 1995 (capacity 3 tons) were constructed and in use until now.

The conventional smoking rooms have problems of non-uniform drying, it also takes a long time (at least 3 days) to dry rubber sheets and consumes high fuel-wood (1.26 kg/kg dried rubber sheets) (Dejchanchaiwong et al., 2017a; Tekasakul and Promtong, 2008). Computational fluid dynamics (CFD) technique has been widely used to simulate the flow and temperature distribution in the conventional RSS room to study and improve the smoking-room efficiency (Promtong and Tekasakul, 2007; Tekasakul and Promtong, 2008; Dejchanchaiwong et al., 2017a). CFD results showed the variations of temperature up to 15°C in conventional RSS rooms. This is because the inappropriate design, especially hot gas supply and ventilating lids. Tekasakul and Promtong (2008) attempted to redesign the smoking room to improve the flow and temperature distributions inside existing smoking room. Results showed that the optimal RSS rooms (model 1994) contains 154 hot gas supply ducts (Ø50 mm.), and four (0.25 m. x 0.25 m.) and four (0.25 m. x 0.20 m.) ventilating lids at the front and the back sides on the ceiling, respectively. Results showed that thermal efficiency of rubber smoking rooms increased from 6.9% (conventional) to 15.7% (redesign). However, this model was able to reduce the temperature variation and increase thermal efficiency but no change in drying time because the flow is natural. The rubber smoking room with forced convection for faster drying and higher thermal efficiency was later modified (Dejchanchaiwong et al., 2017b). Results presented that the modified rubber smoking room can dry up to 1,500 sheets in 48 hours and save 56% of fuel wood as compared to the conventional dryers. Another successful development was a 7 tons capacity commercial smoking room (TK technician limited partnership, 2020). However, this is not suitable for small cooperatives and flow characteristics is not studied as well. Even though the commercial smoking room was able to reduce drying time compared to conventional smoking room but it needs skillful operators and cost higher than modified smoking room.

In the present study, the high-performance RSS room will be tested. it aims to reduce the drying time to within 24 hours, enhance the thermal efficiency, and provide easy operations.

1.2 Objectives

In the present study, the main objectives are:

1. To study the appropriate drying conditions for the high-performance RSS room.

2. To analyze the energy and exergy of high-performance RSS room to

understand the thermodynamic behaviors.

1.3 Scopes of research work

1.3.1 The high-performance RSS room

The high-performance RSS room in the present study was constructed and is located at Saikao cooperative in Muang district, Songkhla Province, Thailand (Figure 1). The dimensions of the RSS room are 5 m. x 6.0 m. x 2.5 m.; it consists of 2 identical smoking rooms. The furnace (2.0 m. × 2.1 m. × 1.4 m.) is connected to a Ø 1.2 m cylindrical tube for biomass fuel-wood supply. Air flow of 4000 CFM is driven by two blowers, each using a 2.2 kW, 3 phase motor (static pressure 100.84 Pa) with variable speed drive (VSD) connected between the furnace and the drying room.

Figure 1 A high-performance RSS room: manual operation model at Saikao rubber cooperative.

1.3.2 Conditions of study

Parameters of the study are inlet velocity in the range 12 and 14 m/s, moisture content of fuel-wood from 24–55% db. The drying room temperature is maintained at about 60°C.

1.3.3 Output

Analysis of energy and exergy includes thermal efficiency, specific energy consumption (SEC), exergy inflow, exergy outflow, exergy loss and second law efficiency.

Chapter 2

Literature Review and Theory

2.1 Manufacturing process of RSS

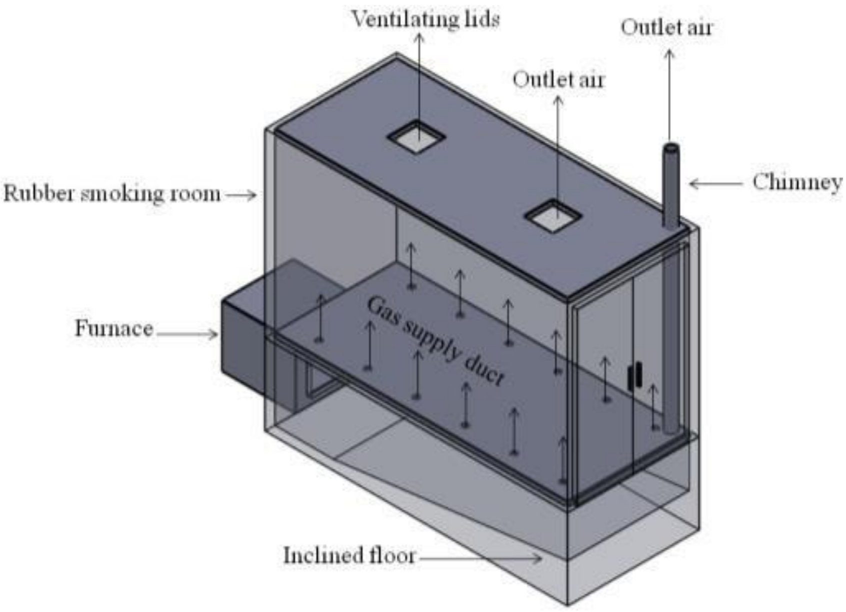
In rubber sheet manufacturing process, rubber fresh latex, containing about 35-40% of dry rubber content (DRC), is collected and delivered to cooperatives. It is diluted with water to achieve the 15-18 %DRC, then 2% wt./vol. of formic acid is added for the rubber to coagulate in the coagulation tanks. The mixture is stirred to mix well and all surface bubbles are removed because the bubbles are the cause of quality degradation of the rubber sheets. The thick slabs of the rubber sheets are separated by separators in the coagulation tank and then left to form lumps of coagulum within 3-4 hours. The hardened rubber slabs are then removed from the coagulation tank and squeezed to form thin rubber sheets (3-4 mm. thick) by milling. Finally, the rubber sheets are placed in the carts inside the RSS room before drying. RSS products are expected to pass grade3 standard in which slight traces of rust and dry mould on the packaging and interior sheets should exceed 10% of the bales sampled. Small bubbles, slight specks of bark, and slight blemishes in color are permissible.

2.2 Ribbed smoked sheet (RSS) room

2.2.1 Conventional RSS room

The present RSS rooms consist of two models; year 1994 and 1995 models (Kalasee et al., 2013). The differences between two models are the size of the rooms, and the geometry and arrangement of the hot gas supply ducts. The capacity of year

1994 model room is 1.5 tons dried rubbers sheets, while, capacity of the year 1995 model room is doubled (3 tons). Heat and smoke generated from fuel wood burning are used to dry the rubber sheets by natural convection. The room floor contains 12 100 mm-diameter hot gas supply ducts. Two 0.6 m. × 0.6 m. ventilating lids are installed at the ceiling for the humid gas outlet. An 8-m long chimney with a 200 mm diameter is used for gas exhaust to create an air drafting as shown in figure 3. Generally, drying time of RSS is at least 3 days to reduce moisture content from about 40% to 0.4% dry basis. Specific fuel-wood consumption is about 1.12-1.48 kg per kg of dried rubber sheets (Kalasee et al., 2013).

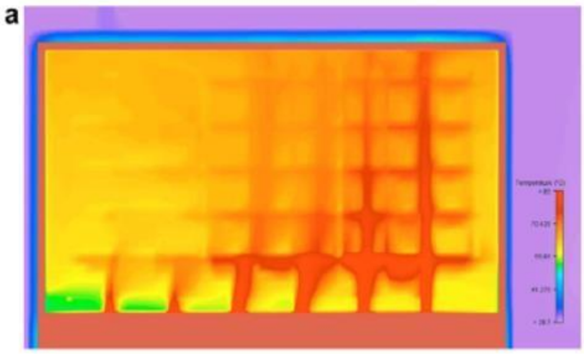


(a)

Figure 2 Schematic diagram of conventional RSS rooms year 1994 model.

2.2.2 Modified RSS room

Kalasee et al. (2013) improved the smoking process by reducing the heat loss though the draft tube and ventilating lids, and adjusted the temperature distribution to be more uniform. The supply ducts were modified by using the impaction plate over the hot gas supply ducts and the perforated steel sheets (1/4 inches) holes over the rubber hanging carts to distribute the temperature. Results showed that the fuel-wood consumption could be reduced by about 45% and thermal efficiency was enhanced by 13%. Computation fluid dynamics (CFD) technique was then used to simulate the flow and temperature distributions in the conventional RSS room (Promtong and Tekasakul, 2007). CFD simulation results presented that the variation of temperatures was as large as 15°C in a conventional RSS room, as shown in Figure 4. This is a result of inappropriate design of the RSS room, especially hot gas supply and ventilating lids. The uniformities of temperature and velocity distributions needed to be improved to reduce the fuel-wood consumption and enhance the product quality.



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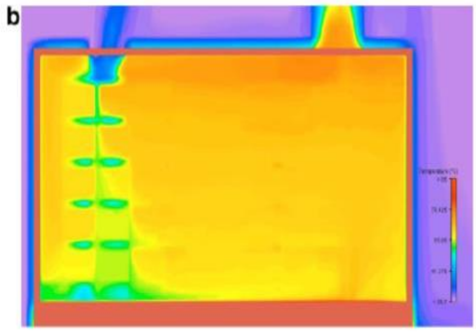

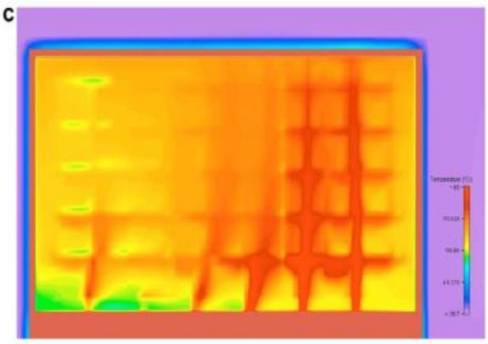

(b) (c)

Figure 3 Temperature distributions in conventional RSS room (a) right plane (midplane (c) left plane (Promtong and Tekasakul, 2007).

Tekasakul and Promtong (2007) subsequently applied the CFD technique to develop a more energy efficient RSS room. Size, position and number of gas supply ducts and ventilating lids were redesigned. The new rubber smoking room of size 2.5 m. × 6.0 m. × 3.5 m. contains 154 50 mm-diameter hot gas supply ducts, and four 0.25 m. × 0.25 m. and four 0.25 m. × 0.20 m. ventilating lids, as shown in Figure 5. Test results showed that the average temperature difference between any planes was 4-7°C and modified RSS room was able to save 66.7% fuel wood consumption compared to a conventional RSS room with 15.7% thermal efficiency (Dejchanchaiwong et al., 2019). Even though, this model is able to reduce variation in temperature and flow which results in uniform drying and reduction in fuel-wood consumption but no change in drying time because the flow is still natural (Dejchanchaiwong et al., 2019).

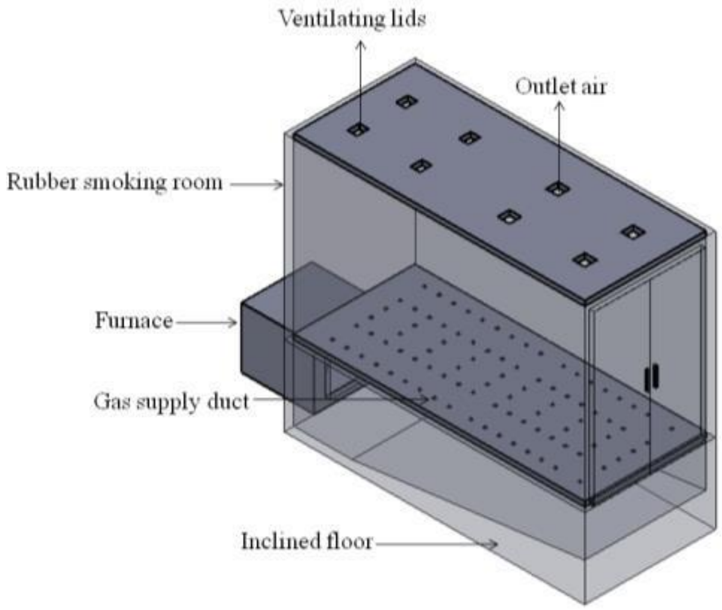

Figure 4 Schematic diagram of an improved RSS room model.

The RSS rooms using forced convection to reduce the drying time and enhance the thermal efficiency were designed by a few researchers. Dejchanchaiwong et al. (2017a) redesigned the room to improve flow characteristics using CFD with forced convection and a recirculation system. This modified RSS room with forced convection can dry up to 1500 sheets in 48 hours and save 55% of the energy as compared to a conventional RSS room (Kalasee et al., 2013). Moreover, another commercial development of 5-7 tons capacity RSS room with forced convection is available in the market as shown in Figure 6. This model of the RSS room can reduce the drying time from 72 hours to 24-48 hours. It has the potential to reduce energy and drying time.

However, maximum production capacity of the rubber cooperative is usually from 1.5 to 3 tons per day. Hence, this design is not suitable for individual cooperative.

Figure 5 Commercial development of high-performance RSS room

(TK technician limited partnership, 2020).

Moreover, understanding the factors affecting the rubber sheet drying (velocity, temperature and relative humidity) can help improve the efficiency of RSS room and enhance the quality of dried products (Tekasakul et al., 2007). temperature inside the rubber smoking room should be maintained between 45-50°C during 0-24 hours and then constant at 60°C. Ajani et al. (2018) showed the optimal velocity for faster drying at 2.5 m/s. Therefore, not only the appropriate design but also the suitable factors can reduce the drying time and the fuel-wood usage, improve the quality of the sheets and enhance the drying efficiency (Ajani et al., 2019)

Exergy is the maximum work can be obtained by the system depending on environment. The second' law of thermodynamics analysis of exergy requires values of exergy inflow, exergy outflow and exergy losses from the system. Exergy efficiency was found to be highest during solar drying of jackfruit under maximum solar radiation.

Temperature of hot air influenced the to exergy efficiency (Chowdhury et al., 2011). According, Increase of exergy efficiency was fastest in the case of pumpkin drying under of highest hot air temperature (Akpinar et al., 2006). In experimented of drying of mulberry thin drying. Exergy efficiency depended on the difference between temperature of hot air at inlet and outlet of the drying chamber (Akbulut and Durmuş, 2010). Moreover, mass flow of hot air passing into the chamber effected exergy efficiency. In drying of rosemary in hybrid-solar dryer with forced convective, exergy efficiency was highest at the maximum air velocity (Karami et al., 2021).

2.2.3 Theory of drying

Drying is a heat and mass transfer processes consisting of the removal of water from internal to the surface of materials. The rates of water removal depend on type of materials. The basis of drying mechanisms consists of the heat transfer for evaporation of liquid and the mass transfer of liquids and vapors within the materials and vapors on surface. These two processes occur simultaneously. The elements which control the rate of each process determine the rate of drying. The duration of drying is divided to 3 stages.

1. Initial period: Temperature of the product increases until reaching the wet bulb temperature. The water evaporated in this period is the free water which does not bind to other molecules. Generally, initial period is quite difficult to observe because it occurs instantaneously.

2. Constants rate period: The initial linear reduction of the average moisture content as a function of time may be observed. Water is evaporated from the surface of the product and the temperature of product remains constant and highest causing water to move from the interior to the surface for evaporation. The variations of drying are temperature, humidity, direction and rate of flow. The constant rate of drying depends on heat or mass coefficient, heat transfer on surface, and temperature difference.

3.Falling rate period: The moisture content of the product approaches the critical moisture content. The water is moved from the interior to the surface. The evaporation in this period can be difficult, hence the slope of the drying rate curve becomes less steep and eventually tends to level off at a long time. The variations depend on characteristics of the products.

2.2.4 Energy and exergy analysis

Energy conversion efficiency

First law of thermodynamics, also known as the conversation of energy principle, is one of the most fundamental principles to discuss the efficiency of energy conversion processes and impact of energy conversion on the environment. Energy can be transferred to a system in three forms; heat (Q), work (W) and mass flow (m). The energy efficiency indicates how well an energy conversion or transfer process is accomplished. In the present study, the specific energy consumption (SEC) the thermal efficiency of a dryer (η_{dryer}) are applied to evaluate the energy conversion efficiencies.

SEC (Specific energy consumption) is the ratio of total supplied energy in rubber sheet drying and mass of water evaporated. It can be calculated as:

$$SEC = \frac{P_t}{W} \tag{1}$$

Where is P_t the total supplied energy into RSS dryer (kJ) and W is the mass of water evaporated (kg)

Thermal efficiency is a measure of the performance of the rubber smoking dryer. It can be calculated from:

$$\eta_{dryer} = \frac{m_L L}{HV_{wood} m_{wood} + E_e} \tag{2}$$

where m_L is the mass of water evaporated (kg), L is the latent heat of vaporization (kJ/kg), HV_{wood} is the heating value of the fuel-wood (kJ/kg), m_{wood} is the total mass of fuel-wood (kg) and E_e is the total electricity (kJ).

The dried materials are usually used in terms of percentage of the moisture content (MC). In this research, the moisture content is calculated on dry basis. Initial MC of rubber sheet samples is about 40% db and the final MC is 0.4% db Dry basis moisture content can be determined from:

$$\%M_d = \frac{W_w}{W_d} \quad (3)$$

where W_w is the weight of water and W_d is the weight of the dried rubber sheet.

Moisture ratio is ratio between moisture in rubber sheet at any time to initial moisture of rubber sheet.(Jeentada et al., 2021)

$$MR = \frac{M_t}{M_i} \quad (4)$$

where MR the is moisture ratio (-), M_t is the moisture content of the rubber sheet at any time (g water/g dry matter) and M_i is the initial moisture content of rubber sheet (g water/g dry matter).

Thermal efficiency, specific and specific energy consumption are critical performance indicators.

Exergy analysis

Exergy analysis is a powerful tool for developing, evaluating, and improving an energy conversion system. The exergy concept has gained considerable interest in the thermodynamic analysis of thermal processes since the first law analysis has been insufficient from an energy performance standpoint. The system energy balance is not sufficient for the possible finding of the system imperfections. Exergy is the maximum useful work that could be obtained from the system at a given state in specified environment. Reversible work is the maximum useful work that can be produced (or the minimum work that needs to be supplied) as a system undergoes a process between two specified states. The exergy destroyed or lost work is the wasted work potential during process as a result of irreversibility, defined by the difference between the reversible work and useful work. In the present study, the exergy will be analyzed to select the appropriate design and operational procedure for better performance. Also, exergy-based methods can be used to improve economic and environmental assessments, as shown in Figure 7. Energy and exergy modeling techniques are widely used to analyze the energy utilization assessments.

The exergy of a mass flow of the smoking room can be written as:

$$Ex = (u - u_0) + P_0(v - v_0) + \frac{V^2 - V_0^2}{2} + g(z - z_0) - T_0(s - s_0) \qquad (5)$$

where is u the internal energy (kJ/kg), P_0 the is ambient pressure (KPa), v is the specific volume , V is velocity (m/s) , g is the gravity force, z is the height (m) , T_0 is the ambient temperature (K), s is the entropy (kJ/kg.K).

The exergy of a steady flow process in a system with negligible potential energy change may be written as

$$Ex = m_a Cp_a * [T - T_0 - T_0 \ln \frac{T}{T_0}] \quad (6)$$

where m_a is the mass of air (kg), Cp_a is the average specific heat of the drying. T the reference temperature at outlet (K) and T_0 is the ambient temperature (K)

For non-steady flow process in a system, exergy balance can be written as

$$Ex_{in} - Ex_{out} - Ex_{destroyed} = \Delta Ex_{system} \quad (7)$$

where Ex_{in} is the inlet exergy (kJ/kg), Ex_{out} is the outlet exergy (kJ/kg), $Ex_{destroyed}$ is the destroyed exergy (kJ/kg), ΔEx_{system} is the exergy change of system (kJ/kg).

The loss exergy $\sum Ex_{loss}$ during the drying process can be written as (Naemsai et al., 2015):

$$\sum Ex_{loss} = \sum Ex_{in} - \sum Ex_{out} \quad (8)$$

The exergy efficiency is the ratio of exergy outlet and exergy inlet. It can be calculated as:

$$\eta_{exergy} = \frac{Ex_{out}}{Ex_{in}} \quad (9)$$

Exergy control volume of furnace

The exergy for the control volume (furnace) including inlet exergy, outlet exergy and loss exergy in the furnace used in calculation of exergy efficiency represented Figure 6. can be calculated Eqs 8, 9, 10 and 11

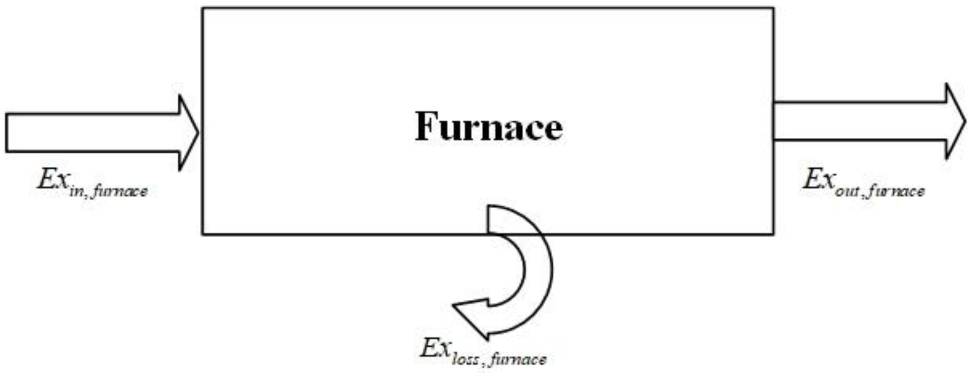

Figure 6 Exergy control volume of furnace

Inlet exergy of furnace generated from the fuel-wood burning inside furnace can be calculated.

$$Ex_{in,furnace} = m_{wood} HV_{wood} \eta_{th} + kWh * 3.6 \quad (10)$$

Where η_{th} is the Carnot efficiency and kWh is the electricity consumption (kilowatt-hour) used in drying. The outlet exergy from the furnace can be calculated from

$$Ex_{out,furnace} = m_a Cp_a \left[T_{out} - T_{amb} - T_{amb} \ln \frac{T_{out}}{T_{amb}} \right] \quad (11)$$

where m_a is the mass of air (kg), Cp_a is the average specific heat of the drying air ($\frac{kJ}{kg.k}$), T_{out} the temperature at outlet (K) and T_{amb} is the ambient temperature (K).

The exergy loss can be calculated from Eq (9)

Exergy control volume of smoking room

The exergy for the control volume (smoking room) including inlet exergy, outlet exergy and loss exergy in the smoking room used in calculation of exergy efficiency represented Figure 6. can be calculated Eqs 8, 9,12 and 13.

$$Ex_{in,smokingroom} = m_a Cp_a \left[T_{out} - T_{amb} - T_{amb} \ln \frac{T_{out}}{T_{amb}} \right] \quad (12)$$

And

$$Ex_{out,smokingroom} = m_a Cp_a \left[T_{out} - T_{amb} - T_{amb} \ln \frac{T_{out}}{T_{amb}} \right] \quad (13)$$

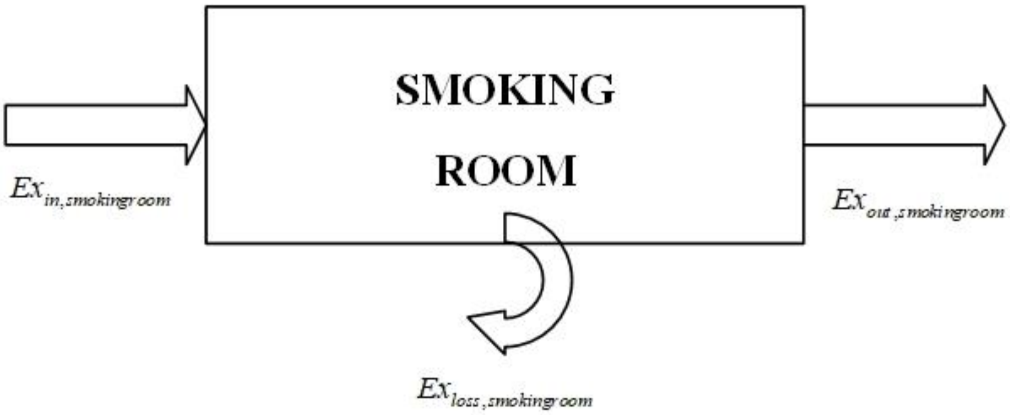

Figure 7 Exergy control volume of drying room

Chapter 3

Research Methodology

This chapter is described to research methodology, indicator, plan and procedures.

3.1 Description of RSS room

The dimensions of the RSS room are 5 m. x 6.0 m. x 2.5 m.; it consists of 2 identical smoking rooms. The furnace (2.0 m. × 2.1 m. × 1.4 m.) is connected to a Ø1.2 m cylindrical tube for biomass fuel supply. Air flow of 4000 CFM is driven by two blowers, each using a 2.2 kW, 3 phase motor (static pressure 100.84 Pa) with a variable speed drive (VSD) connected between the furnace and the drying room. The combustion chamber (1.0 x 1.0 x 1.65 m). A 40 tubes Ø3.8 cm designed for protection from fire sparks. The duct diameters were: exhaust 0.35 m, fresh air mixing inlet 0.3 m and blower inlet 0.35 m. The recirculation duct had a 0.35 m x 0.35 m square cross section. There are 40 Ø8 cm hot air tubes at the floor of the smoking. Ceiling of smoking room, there are 4 ventilating lids (0.2x0.2 m.) on the rear and 1 ventilating lid (0.5x0.5 m.) at front of the smoking room. Hot air recirculation is located above of ceiling.

3.2 Experimental procedure

Three fully loaded carts with natural rubber sheets (approximately 1500 sheets) are placed in RSS room. The weights of three rubber sheet samples at M1, M2 and M3 positions in the front car cart are measured by a weighting balance before feeding fuel wood is weighted by a weighting balance and then burn in a furnace to generate hot smoke. Size of fuel-wood supplied to the furnace not over Ø4 inches. During 0-12, 13-

24 and 25-36 of drying, fuel-wood consumption rate is about 30, 20 and 15 kg/h Hot air is supplied through the blower to the drying room. The variable speed drive is used to vary the speed of the blower motors to control the velocity inlet (V1). Hot smoke is mixed with fresh air to maintain the temperature below 60°C. A temperature data is recorded by data-logger at 2-minute intervals. Hot and humid air is continuously removed from the drying room through the exhaust duct on the top. Temperature velocity, weights of three rubber sheet samples and fuel wood are recorded on an hourly basis until the rubber sheet MC reached 0.4% db**.**

Type-K thermocouples are installed to measure the temperature at 6 positions in 3 planes (T1-T6), one position at the recirculation duct (T7), one at the inlet duct (T8), one in the mixing chamber (T9) and another for ambient air temperature measurement (T10) recorded with data logger (Yokogawa, FX112-2-4) at 2-minute interval. Samples of rubber sheets (M1-M3) and recorded at every 3 hours by a weighting balance (Shimadzu, ELB3000). Masses of their accumulated fuel-wood used in drying by a weighting balance (Defender, 2000).

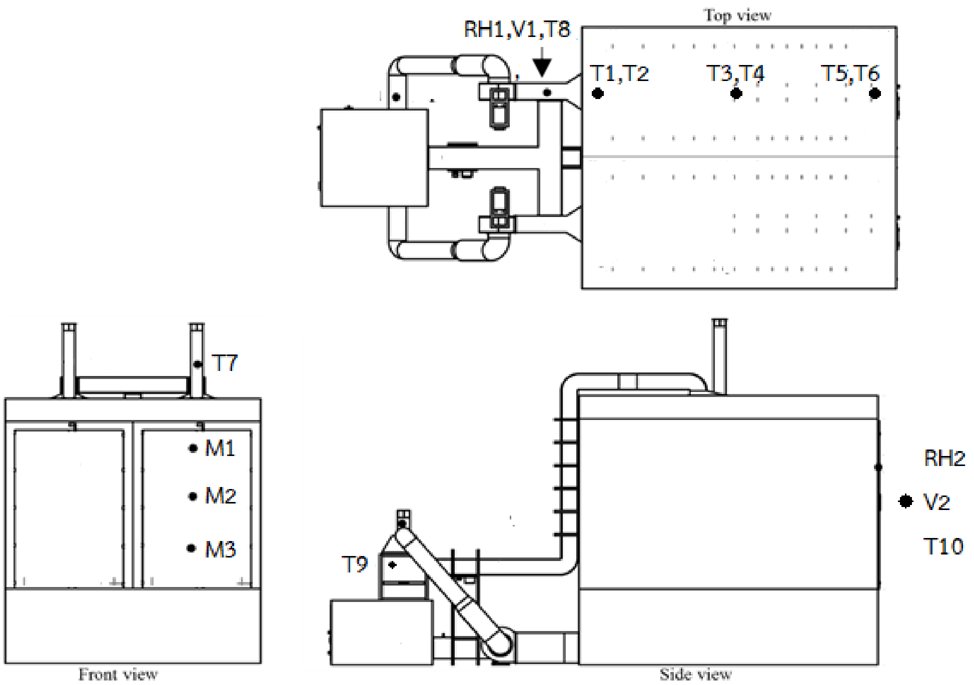

Figure 8 The positions of temperature, velocity and RH measurement in the RSS

The moisture content of fuel-wood is monitored by measuring the moisture content of fuel-wood every week. 3 samples of fuel-wood about Ø 8-10 cm. to oven used temperature 105±2 °C and 72 hours for find to final moisture.

3.3 Experimental conditions

The inlet velocity of hot air varies between 12 and 14 m/s while the moisture content of fuel-wood used between 24-55% db for the all experiments. Recirculation of hot air is 0%, 30% and 40% during 0-12h, 12h-24h and after 24h drying hour, respectively.

3.4 Performance evaluation

Specific energy consumption, and thermal efficiency, are analyzed using Eq. 1 and 2, respectively. Second' law efficiency is calculated using Eq.8.

Chapter 4:

Results and discussion

4.1 Effect of fuel-wood moisture content and fuel-wood supply rate

The moisture content (MC) fuel-wood and supply rate are important factors to control temperature in RSS smoking room not to exceed 60°C to prevent bubble and brown effect on rubber sheets. In all experiments about 1500 sheets of RSS were used for drying. There values of fuel-wood moisture content are 24, 38 and 55% db.

4.1.1 Inlet velocity 12 m/s

For the lowest moisture content of 24% db, average temperature in the drying room during the hour of 0-12, 13-24 and 25-36h were 55.7°C, 72.4°C and 78.0°C, respectively. The ambient temperature was 24.8-31.0°C. Total fuel-wood used 986 kgs. The calculated fuel-wood supply rates during 0-12, 13-24, and 24-36h were 31.7, 27.2 and 23.3 kg/h. For medium moisture content of 38% db, average temperature in the drying room during the hour of 0-12, 13-24 and 25-36h were 52.0°C, 58.8°C and 58.9°C, respectively. The ambient temperature was 28.0-34.2 °C. Total fuel-wood used 842 kgs. The calculated fuel-wood supply rates during 0-12, 13-24, and 24-36h were 29.0 kg/h, 25.2 kg/h and 16.0 kg/h. For the highest moisture content of 55% db, average temperature in the drying room during the hour of 0-12, 13-24 and 25-36h were 50.8°C, 58.3°C and 64.7°C, respectively. The ambient temperature was 27.8-32.3°C. Total fuel-wood used 871 kgs. The calculated fuel-wood supply rates during 0-12, 13-24, and 24-36h were 28.3 kg/h, 24.1 kg/h and 18.6 kg/h. All the results of temperature are Figure 9 and Table 1

The temperature distributions in the smoking room for fuel-wood moisture content at 38% db maintained within 60°C. While, it was slightly over 60°C in the case of wet fuel-wood moisture content at 55% db. However, for the dry fuel-wood (moisture content 28% db), the temperature could not be easily controlled within 60°C. The highest average temperatures were 78°C, significantly higher than the allowable 60°C and reduced drying time from 48 hours to 36 hours. (Dejchanchaiwong et al.,2017a)

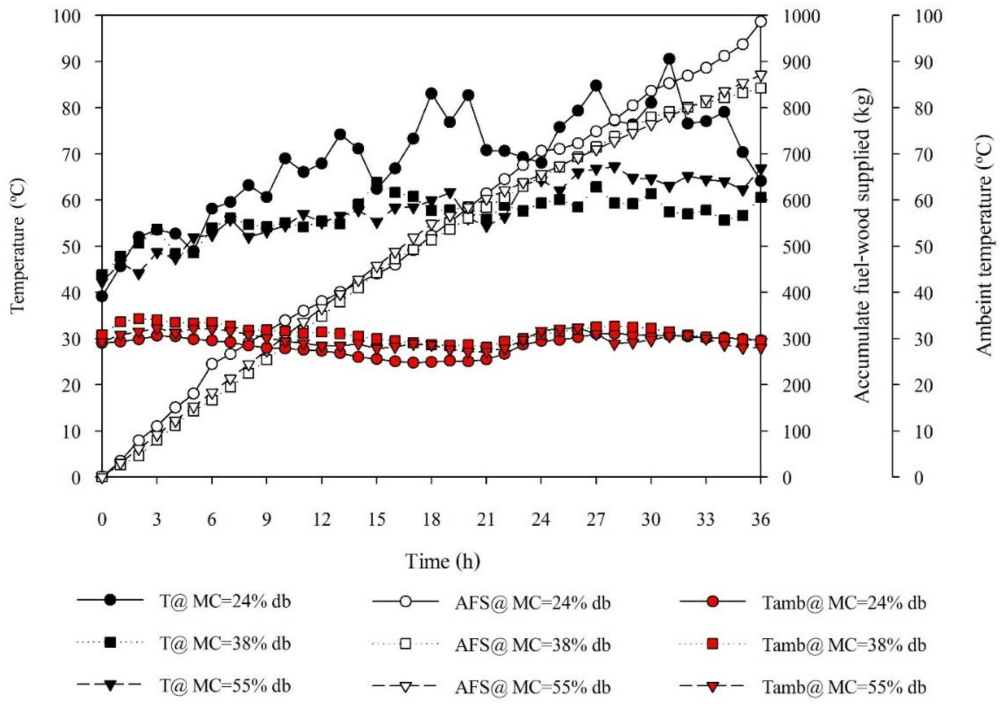

Figure 9 Average temperature inside RSS room, ambient temperature and accumulated fuel-wood

The moisture ratio (MR) and drying rate of RSS indicating how well the water reduction in the rubber sheet are shown in Figures 10 and 11. The reduction of moisture ratio during 0-12, 13-24 and 25-36h for the case of fuel-wood 24% db was from 1.0 to 0.1, 0.1 to 0.03 and 0.03 to 0.02, respectively. The reduction of moisture ratio during

0-12, 13-24 and 25-36h for the case of fuel-wood 38% db was from 1.0 to 0.13, 0.13 to 0.04 and 0.04 to 0.01, respectively. The reduction of moisture ratio during 0-12, 13-24 and 25-36h for the case of fuel-wood 55% db was from 1.0 to 0.17, 0.17 to 0.07 and 0.07 to 0.01. All the results of moisture ratio are Figures 9, 10 and Table 1

The maximum drying rates of rubber sheet samples for fuel-wood MC = 24, 38 and 55% db were 0.29, 0.25 and 0.15 kg/h. The highest moisture ratio reduction and drying rate occurred 0-12h during the constant drying rate period. After 0-12h. rubber sheets drying were slower become water vapor cannot be easily evaporated because water inside rubber sheet has lower therefore diffusion of water from inside rubber sheet to surface is slower accordingly.

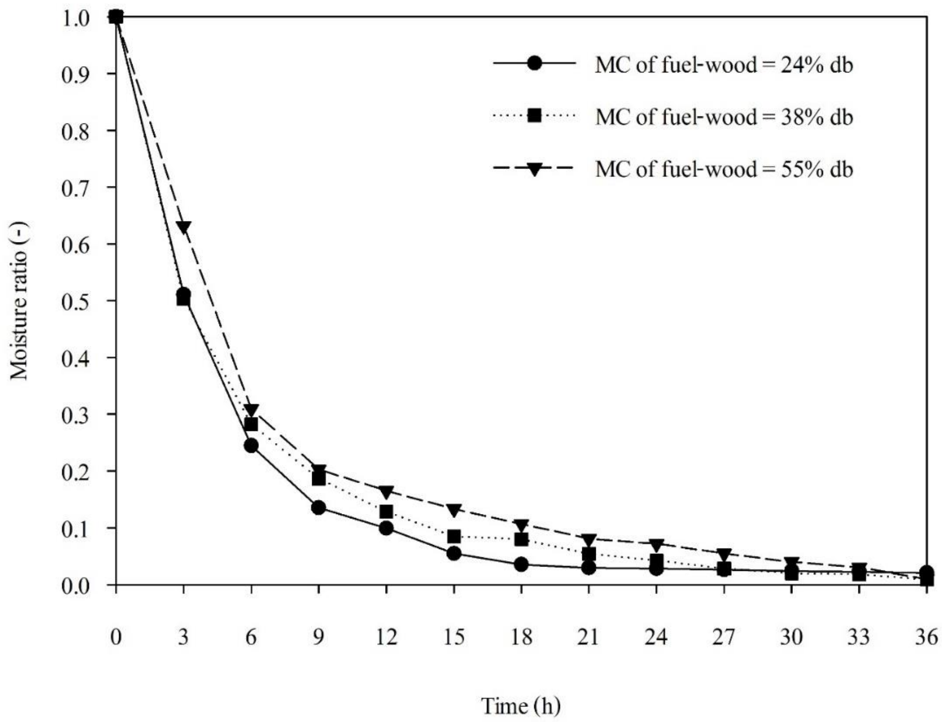

Figure 10 MC ratio in rubber sheet of inlet velocity 12 m/s

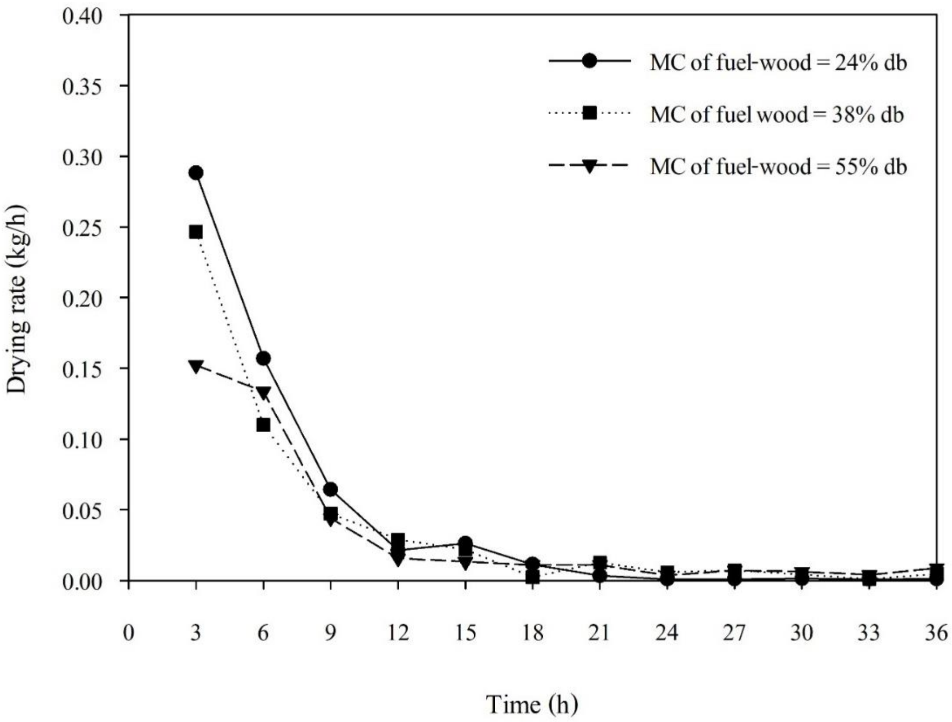

Figure 11 Drying rate in rubber sheet in case velocity 12 m/s

4.1.2 Inlet velocity 14 m/s

For moisture content of fuel-wood 28% db, average temperatures in drying room during the hour of 0-12, 13-24 and 25-36h were 49.1°C, 59.0°C and 62.8°C, respectively. The ambient temperature was 24.0-31.5°C. Total fuel-wood used 765 kgs. The calculated fuel-wood supply rates during 0-12, 13-24, and 24-36h were 27.4, 20.0 and 16.3 kg/h. For moisture content of 53% db, average temperatures in drying room during the hour of 0-12, 13-24 and 25-36h were 45.5°C, 52.3°C and 59.2°C, respectively. The ambient temperature was 42.8-24.8°C. Total fuel-wood used 752 kgs. The calculated fuel-wood supply rates during 0-12, 13-24, and 24-36h were 29.1, 19.8 and 13.9 kg/h. All the results of temperature are Figures 12 and table 1.

Considering, average temperature in smoking room for condition fuel-wood moisture content=24% db has higher than MC% of fuel-wood moisture content=55%

db about 5-7 °C, while, fuel-wood accumulated both conditions nearby but, difference of fuel-wood moisture content effect to average temperature in smoking room.

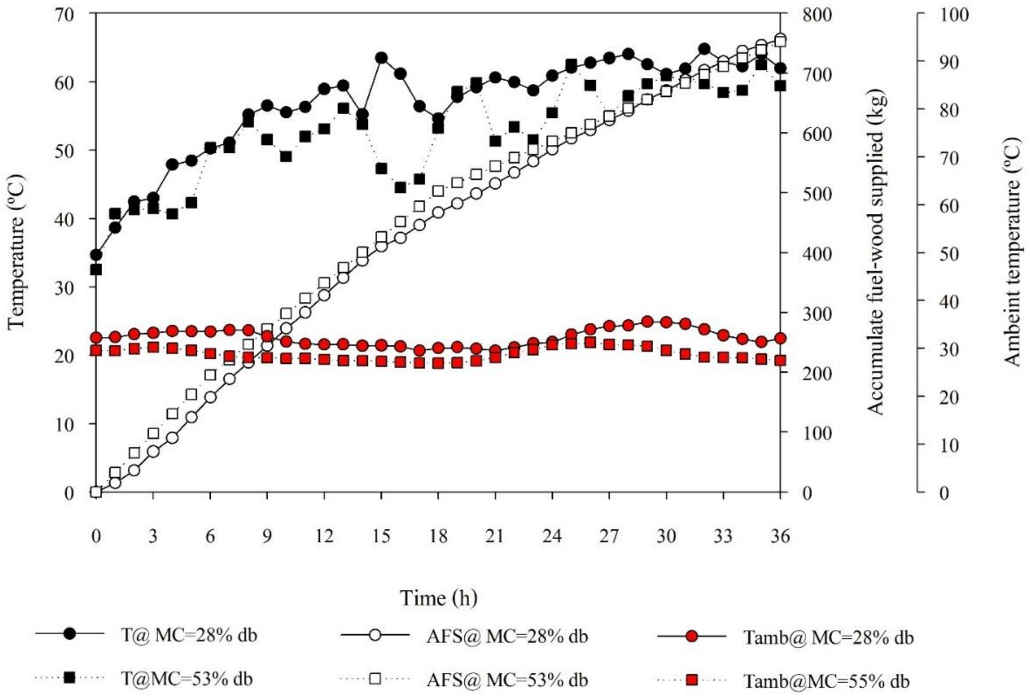

Figure 12 Average temperature inside RSS room, ambient temperature and accumulated fuel-wood

The reduction of moisture ratio during 0-12, 13-24 and 25-36h for the case of fuel-wood 28% db was from 1.0 to 0.1, 0.1 to 0.02 and 0.02 to 0.01, respectively. The reduction of moisture ratio during 0-12, 13-24 and 25-36h for the case of fuel-wood 28% db was from 1.0 to 0.15, 0.15 to 0.07 and 0.07 to 0.04. All results as shown in Figure 13, 14 and Table 1.

The maximum drying rates of rubber sheet samples for fuel-wood moisture content = 28 and 55% db were 0.28 and 0.28 kg/h. Considering, MR reduction of rubber sheet samples for dry fuel-wood (fuel-wood moisture content=24% db) reduce moisture ratio in rubber sheet is faster. Due to average temperature in smoking room is higher effect to reduction of water inside rubber sheet is fast.

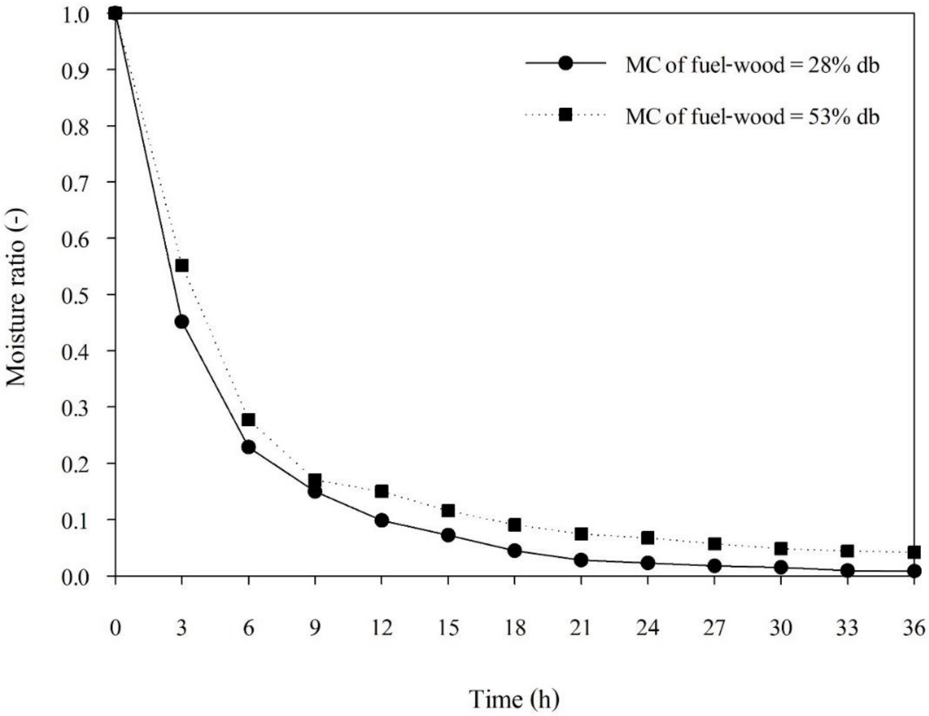

Figure 13 MC ratio in rubber sheet in velocity 14 m/s

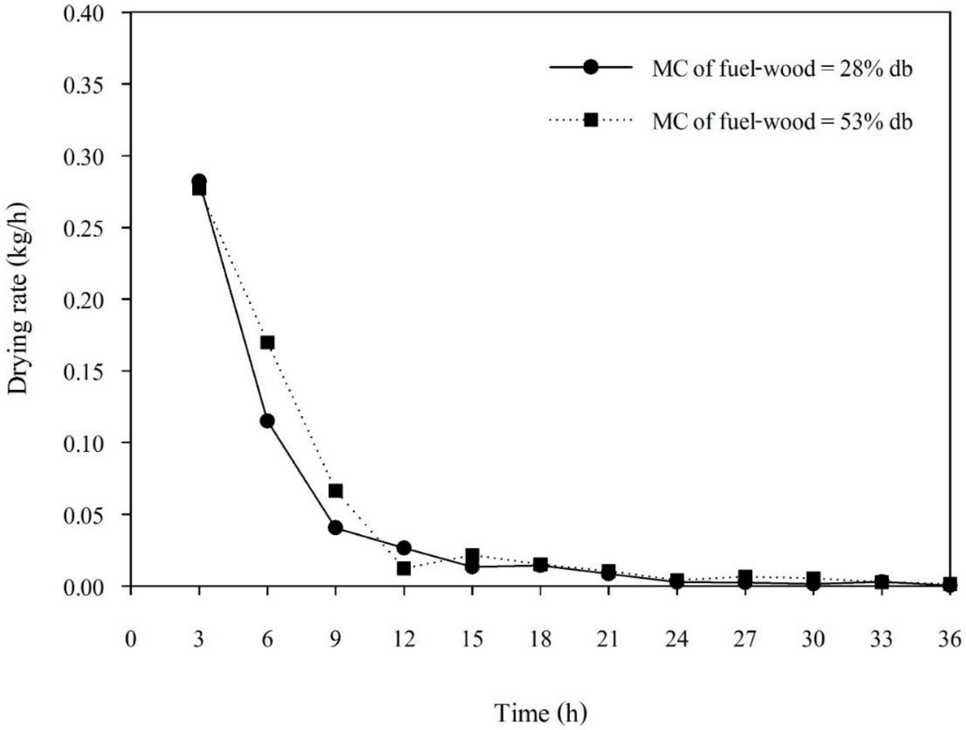

Figure 14 Drying rate in rubber sheet in case velocity 14 m/s

4.2 Effect of inlet velocity and fuel-wood supply rate

The velocity inlet relates mass flow rate of hot air passing rubber sheets and reduction of moisture ratio in rubber sheet. Moreover, control fuel-wood supply rate effect to temperatures in smoking room. For prevented damage of hot air to rubber sheet. In chapter is variation inlet velocity are 12 and 14 m/s.

4.2.1 Dry fuel-wood

For inlet velocity of 12 m/s, average temperatures in drying room during the hour of 0-12, 13-24 and 25-36h were 55.7°C, 72.4°C and 78.0°C, respectively. The ambient temperature was 24.8-31.0°C. Total fuel-wood used 986 kgs. The calculated fuel-wood supply rates during 0-12, 13-24, and 24-36h were 31.7, 27.2 and 23.3 kg/h. For inlet velocity of 14 m/s, average temperatures in drying room during the hour of 0-12, 13-24 and 25-36h were 49.1°C, 59.0°C and 62.8°C, respectively. The ambient temperature was 24.0-31.5°C. Total fuel-wood used 765 kgs. The calculated fuel-wood supply rates during 0-12, 13-24, and 24-36h were 27.4, 20.0 and 16.3 kg/h. respectively. All results of temperatures are in Figure 15 and Table 1.

Considering, average temperature in smoking room for the inlet velocity 12 m/s is higher than. Due to accumulated of fuel-wood in drying more than 221 kgs.

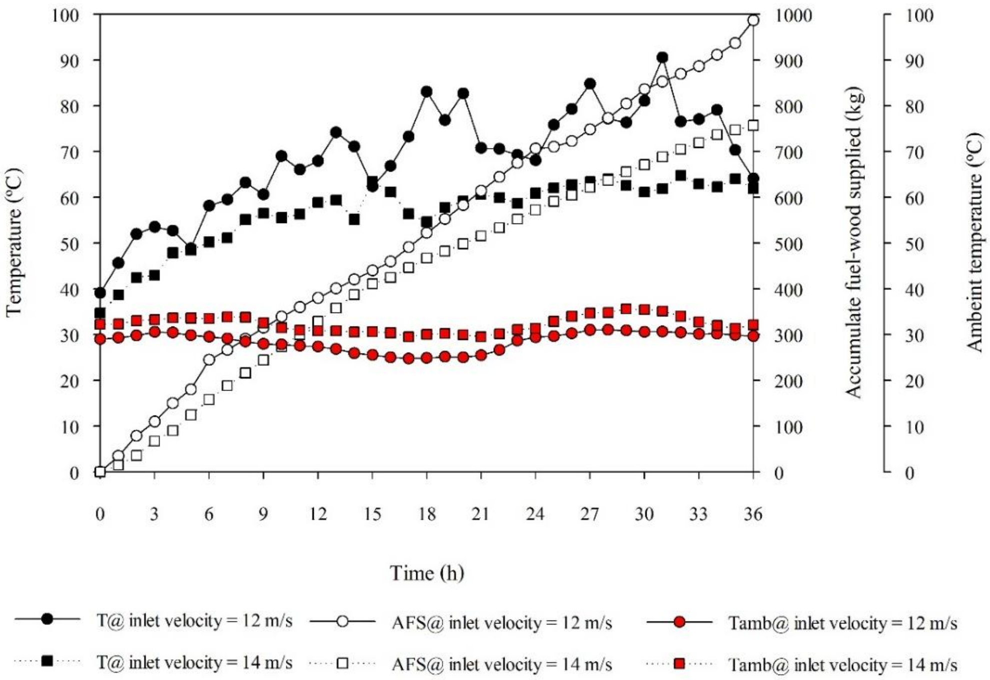

Figure 15 Average temperature inside RSS room, ambient temperature and accumulated fuel-wood

The reduction of moisture ratio during 0-12, 13-24 and 25-36h for the inlet velocity 12 m/s was from 1.0 to 0.1, 0.1 to 0.03. and 0.03 to 0.02, respectively. The reduction of moisture ratio during 0-12, 13-24 and 25-36h for the case of 14 m/s was from 1.0 to 0.1, 0.1 to 0.03 and 0.03 to 0.02, respectively. The maximum drying rates of rubber sheet samples for inlet velocity 12 and 14 m/s were 0.29 and 0.28 kg/h. All results of moisture ratio and drying rate are in Figures 16, 17 and table 1.

Although, for the inlet velocity 12 m/s, average temperature inside smoking room is higher than but characteristics of drying. In first period (0-12 h. of drying) mass flow rate is passing rubber sheet have impact more temperature of hot air.

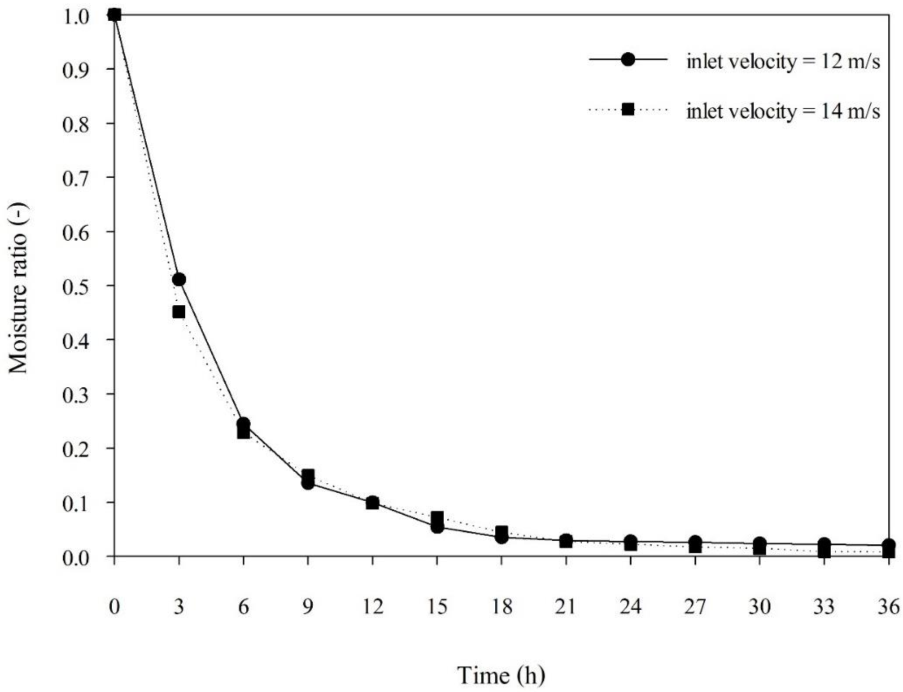

Figure 16 Moisture ratio in rubber sheet in case dry fuel-wood

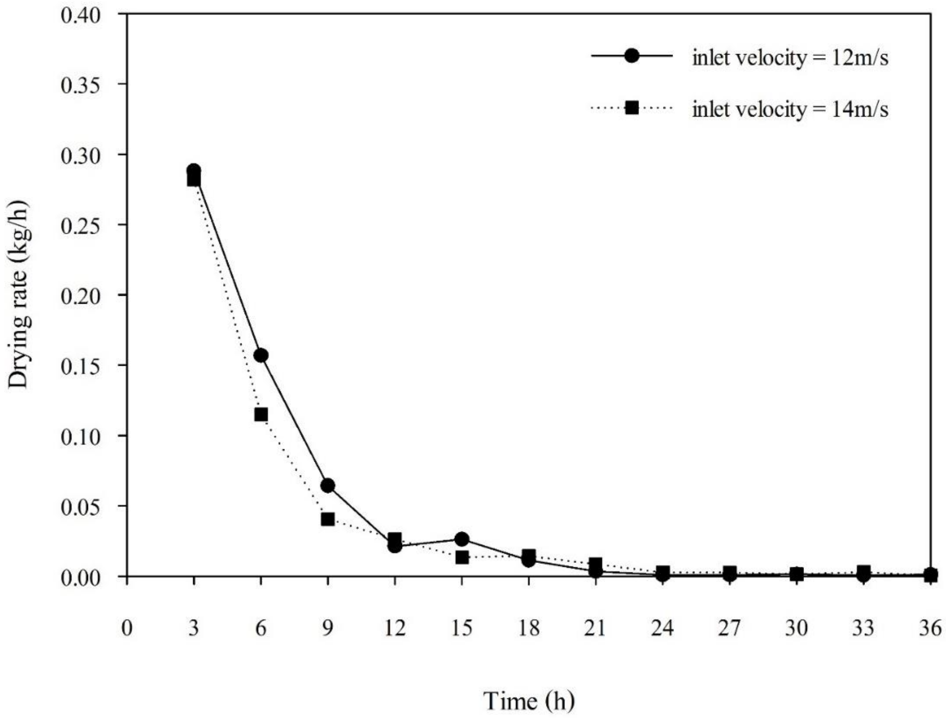

Figure 17 Drying rate in rubber sheet in case dry fuel-wood

4.2.2 Wet fuel-wood

For the inlet velocity of 12 m/s, average temperatures in drying room during the hour of 0-12, 13-24 and 25-36h were 50.8°C, 58.3°C and 64.7°C, respectively. The ambient temperature was 27.8-32.3°C. Total fuel-wood used 871 kgs. The calculated fuel-wood supply rates during 0-12, 13-24, and 24-36h were 28.3, 24.1 and 18.6 kg/h. For the inlet velocity of 14 m/s, average temperatures in drying room during the hour of 0-12, 13-24 and 25-36h were 45.5°C, 52.3°C and 59.2°C, respectively. The ambient temperature was 42.8-24.8°C. Total fuel-wood used 752 kgs. The calculated fuel-wood supply rates during 0-12, 13-24, and 24-36h were 29.1, 19.8 and 13.9 kg/h. All results of temperatures are in Figure 18 and Table 1.

Considering, average temperature inside smoking room, result for inlet velocity 12 m/s is higher due to accumulated of fuel-wood is higher.

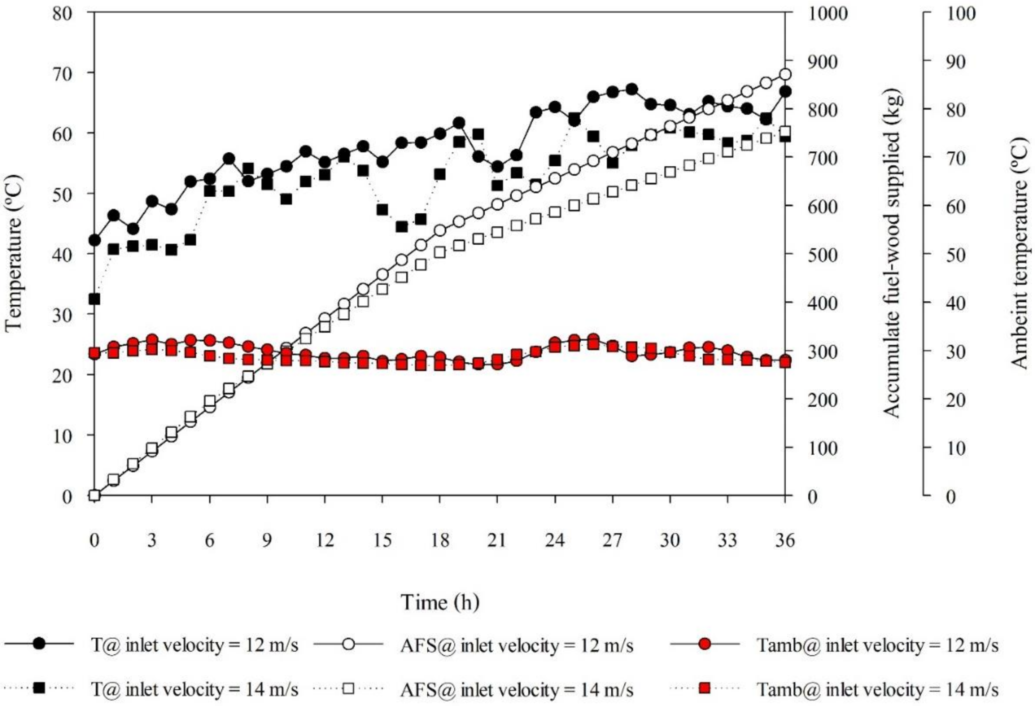

Figure 18 Average temperature inside RSS room, ambient temperature and accumulated fuel-wood

The reduction of moisture ratio during 0-12, 13-24 and 25-36h for the inlet velocity 12 m/s was from 1.0 to 0.17, 0.17 to 0.05 and 0.05 to 0.03, respectively. The reduction of moisture ratio during 0-12, 13-24 and 25-36h for the inlet velocity 14 m/s. was from 1.0 to 0.15, 0.15 to 0.07 and 0.07 to 0.04, respectively. The maximum drying rates of rubber sheet samples for inlet velocity 12 and 14 m/s were 0.15 and 0.27 kg/h. All results of MR and drying rate are shown in Figures 19, 20 and Table 1

MR reduction of the rubber sheet during 0-12 h. of drying for the inlet velocity 14 m/s is faster. Due to in first period of drying hot air mass flow rate passing rubber is higher. Effect to evaporated of water inside rubber sheet is higher accordingly.

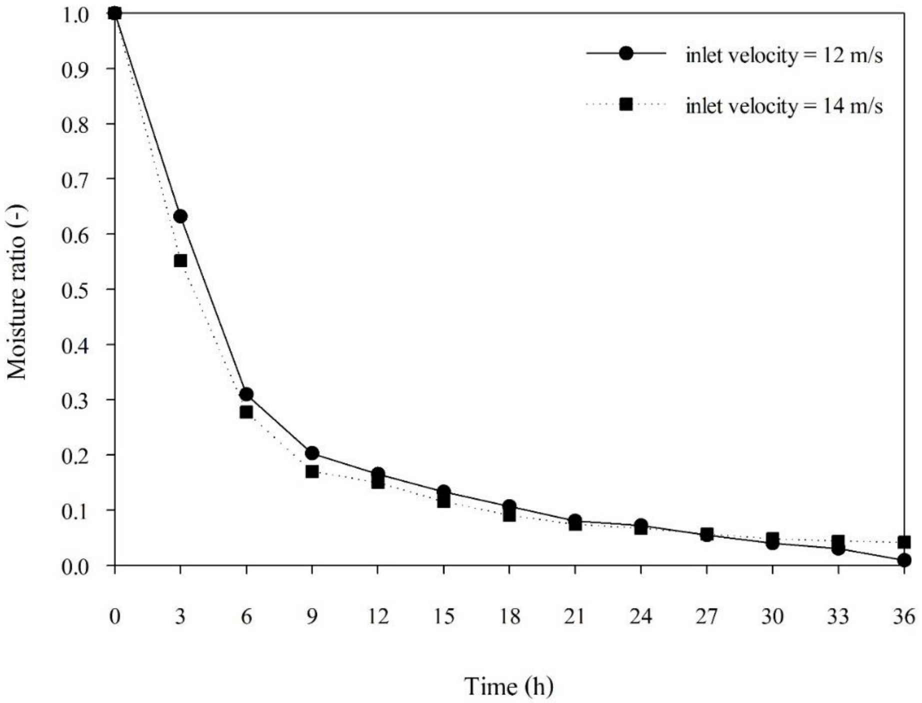

Figure 19 MC ratio in rubber sheet in case wet fuel-wood

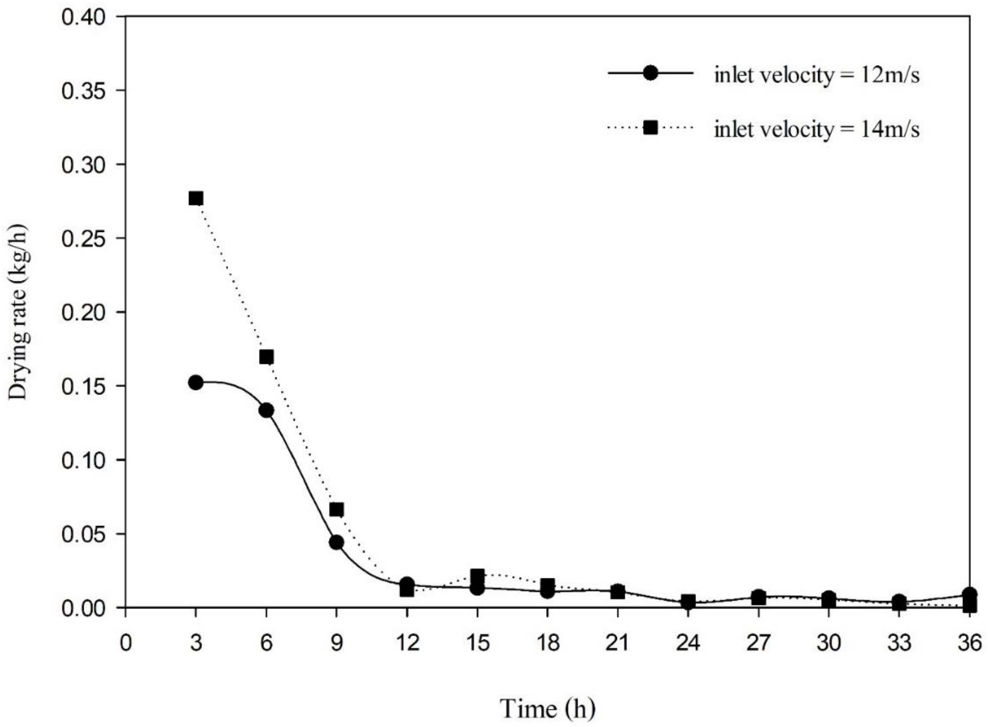

Figure 20 Drying rate in rubber sheet in case wet fuel-wood

Table 1 all results of experiments

Condition	Parameter	During of drying time		
		0-12th	**13-24th**	**25-36th**
Inlet velocity 12 m/s, fuel-wood moisture content 24% db	Temperature avg. (°C) Fuel-wood supply (kg/h) MC ratio Drying rate (Kg-water/h/sheet)	55.7±13 31.7 1.0-0.09 0.28-0.02	72.4±9.8 27.2 0.09-0.03 0.02-0.01	78.0±7.5 23.3 0.03-0.02 0.01-0.005
Inlet velocity 12 m/s, fuel-wood moisture content 38% db	Temperature avg. (°C) Fuel-wood supply (kg/h) MC ratio Drying rate (Kg-water/h/sheet)	52.0±5.6 29.0 1.00-0.13 0.24-0.02	58.8±3.7 25.2 0.13-0.04 0.02-0.01	58.9±2.9 16.0 0.04-0.01 0.01-0.005

Condition	Parameter	During of drying time		
		$0\text{-}12^{th}$	$13\text{-}24^{th}$	$25\text{-}36^{th}$
Inlet velocity 12 m/s, fuel-wood moisture content 55% db	Temperature avg. (°C)	50.8±6.9	58.3±5.7	64.7±3.2
	Fuel-wood supply (kg/h)	28.3	24.1	18.6
	MC ratio	1.0-0.16	0.16-0.07	0.07-0.01
	Drying rate (Kg-water/h/sheet)	0.15-0.02	0.02-0.01	0.01-0.005
Inlet velocity 14 m/s, fuel-wood moisture content 28% db	Temperature avg. (°C)	49.1±8.3	59.0±5.8	62.8±3.5
	Fuel-wood supply (kg/h)	27.4	20.0	16.3
	MC ratio	1.00-0.10	0.10-0.02	0.02-0.01
	Drying rate (Kg-water/h/sheet)	0.28-0.03	0.03-0.02	0.02-0.01

Condition	Parameter	During of drying time		
		0-12th	13-24th	25-36th
Inlet velocity 14 m/s, fuel-wood moisture content 53% db	Temperature avg. (°C)	45.5±7.3	52.3±5.2	59.2±3.5
	Fuel-wood supply (kg/h)	29.1	19.8	13.9
	MC ratio	1.00-0.15	0.15-0.07	0.07-0.04
	Drying rate (Kg-water/h/sheet)	0.28-0.02	0.02-0.01	0.01-0.005

4.3 Thermal analysis

This section presents and discusses thermal analysis in terms of specific energy consumption (SEC) and thermal efficiency.

The values of inlet velocity used 12 and 14 m/s and fuel-wood moisture contents were 24 – 55% db, during 0-12, 13-24 and 25-36h. of drying, percentage of hot air recirculation was approximately 0%, 30% and 40%. The SEC (specific energy consumption) between is 13.5-16.2 MJ/kg of water evaporated and thermal efficiency between are 14.0-16.7% as shown in Table 2. Considering, the result of dry (24% db) fuel-wood is the SEC was highest and thermal efficiency was lowest. For the medium (38% db) and wet (55% db) fuel-wood are nearby the same.

Quality of the rubber sheets in the wet fuel-wood highest (100%). This is because the temperature inside smoking room could be easily controlled. For inlet velocity of 14 m/s thermal efficiency when using wet fuel-wood higher than dry fuel-wood as in the previous case. When comparing the effect of velocity for dry fuel-wood, thermal efficiency was higher when the velocity is lower (12 m/s). However, the quality of the rubber sheets was better for the case of higher velocity (14m/s). This is because of the higher heat transfer rate at the surface.

For the case of wet fuel-wood, the SEC and thermal efficiency nearby the same at both velocities. Quality of the rubber sheets were highest It can be concluded that when using wet fuel-wood, inlet velocity of hot air has insignificant impact in comparison to the dry fuel-wood.

Table 2 The results of thermal analysis

Case No.	**Condition**		**Capacity (kg)**	**Drying time (hour)**	**Accumulated Fuel-wood (kg)**	**good quality (%)**	**Overall SEC (MJ/kg of water evaporated)**	**η_{dryer} (%)**
	Inlet velocity (m/s)	**Fuel-wood moisture content (%)**						
1	12	24	1,776	36	986	54.7	16.2	14.0%
2	12	38	1,229	36	842	87.6	13.5	16.7%
3	12	55	1,361	36	871	100.0	13.7	15.2%
4	14	28	1,753	36	765	100.0	16.9	13.4%
5	14	53	1,065	36	752	100.0	13.7	16.5%

4.4 Exergy analysis

Exergy is the maximum useful work obtained from system. Loss of the exergy during process is called exergy destruction.

The values of exergy inflow, exergy outflow and exergy loss calculated from EQS. (7)-(12). The exergy inflow, exergy outflow and exergy loss in the furnace were 8,922.1-5,418.8, 1,539.3-432.1 and 7,382.7-4,986.7 MJ, respectively. The values in the smoking room were 1,539.3–432.1, 519.4–142.9 and 1,019.0–289.1 MJ, as shown in Figure 21 and Table 3. Ratio of exergy inlet to exergy outlet in the furnace varied between 17.8-6.9%. Ratio of exergy inlet to exergy outlet in the smoking room varied between 41.7–32.0 % as shown in Figure 21 and Table 3

The case of inlet velocity 12 m/s and fuel-wood moisture content 24% db has the highest overall exergy efficiency because the fuel-wood was dry and average temperature inside smoking room was highest. Exergy efficiency is direct is depend on the inlet temperature of smoking room. However, the temperature exceeding 60°C caused damage (bubble and dark brown color) to the rubber sheets resulting a low quality.

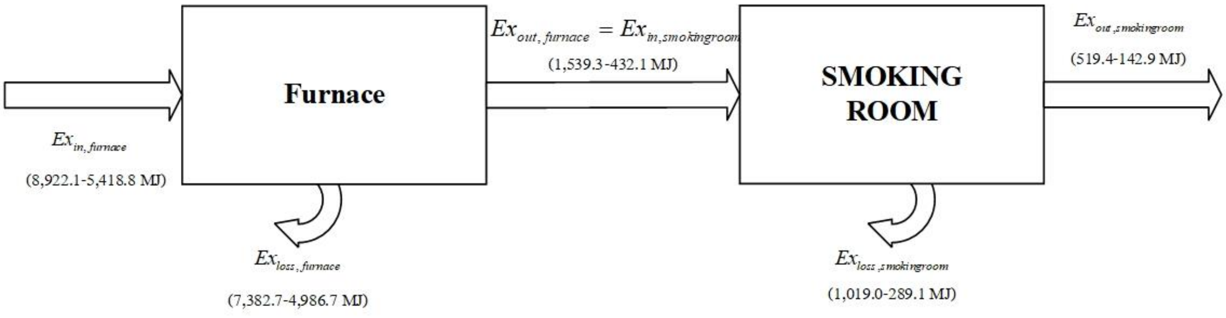

Figure 21 Diagram of exergy balance

Table 3 The results of exergy analysis

Parameters	Furnace			Drying room			Furnace exergy efficiency (%)	Drying room exergy efficiency (%)	Overall exergy efficiency (%)
	Ex_{in} (MJ)	Ex_{out} (MJ)	Ex_{loss} (MJ)	Ex_{in} (MJ)	Ex_{out} (MJ)	Ex_{loss} (MJ)			
12 m/s and fuel-wood 24% db	8,922.1	1,539.3	7,382.8	1,539.3	519.4	1,019.9	17.3%	33.7%	5.8%
12 m/s and fuel-wood 38% db	6,799.2	466.7	6,332.6	466.7	149.2	317.5	6.9%	32.0%	2.2%
12 m/s and fuel-wood 55% db	6,199.9	549.8	5,650.1	549.8	219.7	330.1	8.9%	40.0%	3.5%
14 m/s and fuel-wood 28% db	6,857.2	552.1	6,305.1	552.1	230.1	322.0	8.1%	41.7%	3.4%
14 m/s and fuel-wood 53% db	5,418.8	432.1	4,986.7	432.1	142.9	289.1	8.0%	33.1%	2.6%

Chapter 5 Conclusion

The high-performance smoking room was forced convection used fuel-wood is heat source. The main factor in drying are velocity and temperature of hot air passing rubber sheet. The experiments using inlet velocity and fuel-wood moisture content 12 and 14 m/s, 24-55% db. The range of thermal efficiency between 16.7-12.3 %. The SEC (specific energy consumption) between 13.5-18.3 MJ/kg of water evaporated. The drying time of all conditions have 36h. The inlet velocity 12 m/s and of fuel-wood moisture content = 38% have highest of thermal efficiency. However, quality of rubber sheets for wet fuel-wood moisture content has the highest_(100%) of the both inlet velocities (12 and 14 m/s) This is because the dry fuel-wood not easily controlled the temperature inside smoking room. Concluded, the wet fuel-wood moisture content optimized with smoking room more than the dry fuel-wood moisture content.

The exergy efficiency of the furnace and smoking room have between 2.2-5.8% and 41.7-32.0%. For the inlet velocity 12 m/s and of fuel-wood moisture content = 24% db have the highest of second ‘law efficiency. Considered exergy efficiency temperature at inlet of smoking room is effect exergy efficiency. Exergy efficiency is direct is depend on the inlet temperature of smoking room. However, the temperature exceeding 60°C caused damage (bubble and dark brown color) to the rubber sheets resulting a low quality

Recommended, rubber smoking process must be constantly of the fuel-wood supply for the easily controlled the temperature inside smoking room and quality of rubber sheets in finally.

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APPENDIX

Temperature each point inside smoking room

Condition: inlet velocity 12 m/s, MC% 24 (db)

Hour	T1	T2	T3	T4	T5	T6	T7	T8	Tamb
1.0	31.8	40.7	37.3	37.3	40.9	46.3	41.6	77.3	29.0
2.0	37.3	49.1	43.0	44.1	46.3	53.9	47.2	84.2	29.3
3.0	41.3	54.8	48.2	54.5	53.1	59.8	53.8	106.7	29.8
4.0	42.3	53.9	47.6	68.0	52.7	56.7	53.6	96.6	30.6
5.0	42.3	52.2	45.9	68.3	51.5	56.0	52.7	83.7	30.4
6.0	41.1	48.8	42.6	61.6	47.4	51.7	49.0	65.1	29.8
7.0	43.0	53.6	49.8	82.3	58.0	62.1	58.8	113.5	29.5
8.0	44.9	54.7	52.4	80.2	60.6	64.3	61.0	91.1	29.1
9.0	44.6	55.8	60.4	88.2	63.7	66.7	63.2	110.5	28.4
10.0	43.9	52.7	64.5	79.1	61.6	62.0	60.8	85.2	27.9
11.0	47.1	57.6	72.9	92.3	70.7	73.2	70.1	112.4	27.8
12.0	47.1	55.2	70.5	86.8	67.2	69.4	67.3	99.7	27.5
13.0	48.8	57.9	75.8	87.1	69.3	68.9	70.4	93.1	27.3
14.0	52.5	64.7	78.2	95.6	75.7	78.4	76.4	114.2	26.8
15.0	57.3	64.7	79.1	82.8	70.8	72.0	72.0	80.5	25.9
16.0	58.5	61.1	65.3	68.9	61.3	59.2	62.0	60.8	25.5
17.0	58.6	64.3	68.1	77.7	64.2	68.2	64.9	80.3	25.0
18.0	61.0	69.2	75.2	87.9	71.3	74.8	71.4	104.2	24.7

19.0	67.0	76.9	91.5	97.1	82.4	83.6	84.4	108.7	24.9
20.0	67.6	74.7	81.7	89.7	75.2	72.1	75.6	98.0	25.1
21.0	70.9	77.8	91.4	93.2	80.9	82.0	81.7	97.1	25.0
22.0	69.7	70.4	73.7	75.8	69.5	65.4	70.6	68.9	25.4
23.0	69.1	70.7	70.5	76.2	67.3	69.7	67.0	73.4	26.7
24.0	68.8	69.4	70.0	73.6	66.2	67.8	66.6	70.6	28.7
25.0	68.0	69.3	67.7	74.1	65.7	63.6	66.0	75.0	29.4
26.0	68.7	74.3	78.1	84.8	73.7	75.2	74.0	92.1	29.7
27.0	69.8	76.8	81.6	90.6	76.5	80.6	77.6	105.1	30.3
28.0	74.4	82.4	91.0	96.5	85.6	78.9	86.9	107.2	31.0
29.0	74.0	76.2	79.7	82.4	75.7	74.9	78.0	80.7	31.0
30.0	74.2	75.9	78.4	81.8	74.1	73.6	75.6	80.6	30.9
31.0	73.7	79.6	82.7	94.0	79.4	76.9	78.6	114.5	30.6
32.0	79.3	86.1	98.8	101.1	91.6	86.6	93.3	110.2	30.6
33.0	76.9	75.8	79.0	79.6	77.7	70.3	79.5	72.0	30.4
34.0	75.4	77.4	76.0	84.8	74.1	74.6	73.9	88.8	30.1
35.0	76.8	79.0	81.3	85.4	78.2	73.8	78.4	85.0	30.2
36.0	73.5	70.3	69.7	71.9	69.3	66.9	69.3	63.4	29.9

Temperature each point inside smoking room

Condition: inlet velocity 12 m/s, MC% 38 (db)

Hour	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**Tamb**
1.0	40.0	41.5	46.7	47.8	42.3	44.2	49.9	82.2	30.8
2.0	42.8	47.9	50.1	53.4	45.7	46.8	52.3	80.8	33.6
3.0	44.8	49.0	54.3	58.4	47.9	49.2	57.7	87.9	34.2
4.0	48.6	50.8	59.2	61.4	51.0	50.7	63.1	95.8	34.0
5.0	44.1	48.3	54.0	50.6	46.3	47.1	55.2	66.8	33.5
6.0	44.8	46.1	54.3	51.9	47.9	46.2	56.1	74.6	33.3
7.0	55.0	47.0	57.3	62.6	51.3	50.3	60.2	73.1	33.5
8.0	57.9	46.4	58.7	65.3	53.5	54.7	63.9	79.7	32.7
9.0	56.6	47.2	60.0	60.8	53.3	50.2	60.6	69.6	31.7
10.0	55.6	49.3	57.4	60.9	51.5	50.4	58.6	66.4	31.8
11.0	56.1	50.1	58.2	62.3	52.3	51.7	59.9	68.7	31.6
12.0	54.9	50.2	56.4	59.7	51.2	52.6	58.0	63.2	31.1
13.0	54.8	50.4	54.7	61.0	52.7	58.8	58.1	64.8	31.3
14.0	53.7	50.8	54.4	58.4	52.9	58.8	56.7	62.0	31.0
15.0	55.5	54.1	59.7	62.4	59.0	63.8	59.9	69.0	30.4
16.0	58.7	58.2	64.6	68.2	63.6	69.6	64.0	79.3	29.9
17.0	60.0	55.3	62.4	64.7	62.2	65.1	61.6	68.2	29.4
18.0	59.6	56.6	61.4	63.0	61.2	62.7	61.0	66.3	29.1

19.0	56.7	56.5	57.9	60.8	55.6	58.8	58.4	63.4	28.6
20.0	57.9	55.8	57.5	60.2	56.1	59.6	57.5	59.8	28.4
21.0	57.1	56.8	57.8	62.5	56.2	60.7	57.6	64.1	28.6
22.0	56.5	55.6	57.7	57.4	54.4	53.6	56.0	59.5	28.0
23.0	58.4	57.7	59.4	63.4	54.4	59.6	58.7	65.5	29.3
24.0	58.1	57.7	59.1	59.7	54.5	56.7	57.9	63.0	29.9
25.0	59.2	58.6	59.7	63.6	54.8	59.9	59.1	66.1	30.8
26.0	60.4	58.8	60.6	63.1	56.2	61.4	59.5	64.7	31.4
27.0	59.6	59.7	59.8	60.2	55.3	56.2	58.6	64.1	31.9
28.0	63.2	61.4	63.7	67.1	58.3	63.4	62.9	70.5	32.5
29.0	60.6	59.3	60.3	60.6	56.2	59.1	58.7	60.8	32.6
30.0	59.7	60.1	60.1	61.4	56.3	57.4	59.3	64.9	32.4
31.0	62.2	61.3	62.1	64.5	56.9	60.9	60.6	66.2	32.1
32.0	59.0	57.9	58.7	58.1	54.6	56.2	56.9	57.4	31.4
33.0	58.2	59.4	57.8	59.2	54.0	53.3	57.1	62.6	30.7
34.0	59.6	59.4	58.9	59.4	53.9	55.7	57.0	60.0	30.3
35.0	57.5	56.1	57.0	56.1	52.6	54.5	54.9	54.9	29.9
36.0	57.1	59.5	57.0	59.1	53.2	54.1	56.2	62.3	29.7

Temperature each point inside smoking room

Condition: inlet velocity 12 m/s, MC% 55 (db)

Hour	T1	T2	T3	T4	T5	T6	T7	T8	Tamb
1.0	42.0	40.9	44.7	57.8	43.2	49.6	45.7	73.1	29.2
2.0	40.7	40.7	43.3	51.8	41.5	46.9	43.8	60.7	30.4
3.0	44.0	42.9	46.6	61.1	45.8	51.7	48.8	74.9	31.3
4.0	43.2	42.6	46.3	57.7	44.7	49.9	47.7	67.8	31.2
5.0	46.7	45.1	50.0	64.5	48.8	56.6	52.8	77.9	31.8
6.0	47.4	46.0	51.8	65.2	49.8	54.5	54.0	78.6	31.7
7.0	49.5	47.0	55.8	69.2	52.4	60.6	57.6	84.3	31.4
8.0	48.7	46.2	54.3	59.1	51.7	52.1	55.9	74.7	30.2
9.0	49.7	46.3	55.8	61.9	52.5	52.9	56.8	77.0	29.0
10.0	50.8	46.8	57.5	63.7	54.1	53.9	58.8	76.4	28.5
11.0	53.8	47.9	61.2	66.7	56.5	55.7	62.5	80.8	28.6
12.0	52.3	46.1	59.0	62.2	55.6	55.6	59.5	70.9	28.2
13.0	53.8	46.1	60.0	64.2	55.7	59.3	60.8	72.5	28.1
14.0	56.0	46.6	61.6	64.8	56.9	60.8	62.2	71.6	28.2
15.0	52.9	45.3	58.7	61.3	55.1	58.2	58.8	66.5	27.8
16.0	56.0	47.0	61.5	65.1	58.1	62.4	62.1	70.4	28.2
17.0	56.2	47.7	61.4	65.1	57.4	62.8	61.3	69.4	28.6
18.0	57.5	49.8	62.9	66.6	58.3	64.4	62.8	71.8	29.0

19.0	59.0	52.6	65.1	67.9	60.1	65.3	64.7	72.9	29.0
20.0	53.6	51.2	60.0	59.3	55.0	57.3	59.3	58.9	28.4
21.0	52.1	51.0	56.1	57.6	53.8	56.0	56.3	60.0	28.3
22.0	53.8	51.8	57.3	60.8	54.8	59.5	57.8	65.3	29.0
23.0	60.3	55.9	64.7	69.4	62.5	67.8	64.9	79.7	30.4
24.0	61.7	58.1	66.9	69.0	62.8	67.2	66.4	77.7	31.5
25.0	59.8	57.4	64.8	66.1	59.7	64.5	64.4	69.8	32.3
26.0	63.0	59.9	67.6	71.5	64.1	69.7	67.5	79.6	32.3
27.0	64.3	61.8	69.8	70.9	65.2	68.8	69.0	79.2	31.3
28.0	65.3	62.1	69.0	71.8	65.0	70.2	69.1	78.6	30.7
29.0	62.6	61.1	67.6	68.2	62.5	66.6	67.1	70.9	30.0
30.0	62.8	61.9	67.3	67.2	62.9	65.6	66.8	73.4	30.6
31.0	61.2	60.5	64.9	66.1	61.0	64.7	64.7	68.6	31.3
32.0	63.8	61.4	65.9	69.3	63.1	68.0	66.6	75.5	31.8
33.0	63.2	62.0	67.5	66.2	63.0	64.7	66.8	71.3	30.6
34.0	62.4	61.4	65.4	67.2	61.9	66.0	65.4	70.5	30.2
35.0	61.0	60.6	64.3	64.5	60.2	62.9	63.8	67.0	29.7
36.0	66.0	62.7	68.0	70.4	64.6	69.3	68.4	76.7	29.6

Temperature each point inside smoking room

Condition: inlet velocity 14 m/s, MC% 28 (db)

Hour	T1	T2	T3	T4	T5	T6	T7	T8	Tamb
1.0	34.8	32.9	34.3	36.5	33.1	36.3	36.2	51.7	28.2
2.0	37.8	35.5	38.6	42.1	36.7	41.2	40.5	63.1	28.3
3.0	40.9	39.4	42.2	47.0	40.1	45.1	44.2	67.9	29.0
4.0	41.4	40.2	42.8	48.0	40.6	45.0	44.5	64.8	29.2
5.0	45.3	41.2	50.9	54.8	46.0	49.0	51.7	81.3	29.6
6.0	45.3	44.2	51.2	54.9	46.8	48.5	51.7	75.7	29.6
7.0	46.5	43.8	53.9	58.9	49.1	49.3	54.3	78.3	29.5
8.0	46.5	45.2	54.7	60.4	49.6	50.3	55.2	76.7	29.9
9.0	49.1	49.1	58.9	62.4	53.6	57.9	59.6	82.6	29.8
10.0	51.4	48.5	61.5	65.2	56.1	56.1	62.8	86.7	28.5
11.0	51.5	47.9	60.6	64.5	56.0	52.6	61.4	78.3	27.4
12.0	52.4	47.2	62.5	65.9	57.5	52.4	63.0	82.2	26.9
13.0	55.5	49.9	64.8	66.1	60.1	57.2	66.3	87.6	26.8
14.0	55.7	47.7	65.4	67.2	60.8	59.9	65.3	81.8	26.8
15.0	51.5	48.3	58.7	63.3	55.7	53.8	58.7	63.0	26.5
16.0	61.8	48.0	71.2	70.8	65.0	64.2	70.9	94.6	26.6
17.0	60.1	48.1	67.2	67.6	61.8	62.2	66.9	74.5	26.4
18.0	54.2	47.2	60.5	62.0	56.2	58.2	60.1	60.2	25.5
19.0	52.4	49.1	57.4	60.7	54.2	54.0	57.7	60.5	26.0

20.0	55.2	49.2	60.8	66.1	56.5	58.8	61.2	68.0	26.2
21.0	56.9	51.1	62.8	66.2	58.3	59.9	62.4	66.7	25.9
22.0	57.9	53.2	63.3	68.2	59.2	61.9	63.3	70.2	25.5
23.0	57.5	54.0	62.5	67.1	58.4	60.1	62.2	69.5	26.2
24.0	56.7	54.3	62.0	63.1	57.7	58.6	60.8	62.9	27.0
25.0	58.4	55.4	62.9	68.3	58.8	61.5	62.5	71.5	27.3
26.0	59.3	56.5	64.4	68.0	60.3	63.8	63.6	70.1	28.9
27.0	59.7	57.4	65.0	68.8	60.8	64.7	64.3	71.7	30.0
28.0	61.0	58.5	66.5	70.0	61.6	63.1	65.8	72.4	30.6
29.0	61.0	59.2	66.4	70.1	61.8	65.8	65.7	72.7	30.8
30.0	60.3	58.6	65.7	66.5	61.0	63.3	64.5	66.9	31.5
31.0	59.3	58.8	64.4	64.9	60.2	59.1	63.5	64.8	31.5
32.0	59.6	59.1	63.2	67.1	59.2	63.4	62.9	69.7	31.1
33.0	62.2	60.4	67.3	69.9	62.8	66.1	65.8	71.3	30.0
34.0	61.6	60.7	65.8	67.2	61.1	61.1	64.5	68.4	28.7
35.0	60.8	60.7	64.4	66.2	59.8	61.6	63.4	67.2	27.9
36.0	61.9	61.0	65.7	69.1	61.4	65.3	64.9	71.6	27.3

Temperature each point inside smoking room

Condition: inlet velocity 14 m/s, MC% 55 (db)

Hour	T1	T2	T3	T4	T5	T6	T7	T8	Tamb
1.0	33.6	29.8	33.4	33.5	34.5	30.2	36.7	63.9	28.7
2.0	38.3	37.5	39.1	49.1	42.8	37.5	44.7	77.6	34.5
3.0	39.3	39.2	38.9	49.6	42.7	37.8	44.7	70.7	35.2
4.0	39.9	39.5	39.0	49.7	43.2	37.4	45.2	67.9	35.6
5.0	39.7	39.0	38.6	47.8	42.4	36.6	44.1	62.2	36.1
6.0	41.2	39.3	40.9	50.0	44.6	38.1	46.7	68.5	36.8
7.0	47.2	47.6	50.5	57.1	54.5	45.3	58.3	97.3	40.4
8.0	48.8	47.2	53.4	54.7	53.8	44.4	56.7	78.1	41.4
9.0	53.8	47.8	59.5	55.7	57.9	50.2	61.0	89.0	42.8
10.0	52.1	46.0	56.1	50.8	53.8	50.4	55.1	62.8	41.7
11.0	48.7	44.3	51.4	47.6	50.5	51.8	50.8	57.0	40.4
12.0	51.5	45.5	54.4	51.7	53.8	55.2	54.2	67.7	40.6
13.0	52.8	46.8	56.2	51.8	54.8	56.4	55.7	63.2	39.6
14.0	54.1	47.9	58.3	55.2	57.3	63.9	57.7	72.2	41.7
15.0	53.1	47.8	56.3	52.5	56.1	56.9	56.1	60.1	40.0
16.0	47.1	45.5	48.8	46.3	47.8	48.5	48.2	45.7	39.7
17.0	44.3	44.4	45.1	43.8	44.2	45.1	44.7	42.1	38.4
18.0	44.4	45.2	46.0	47.1	46.0	45.9	46.2	54.2	34.8
19.0	50.1	50.3	56.3	54.2	53.8	54.6	54.0	64.1	25.2

20.0	53.8	54.5	61.1	60.1	57.8	63.8	59.1	77.0	25.1
21.0	55.7	57.3	63.2	59.5	60.0	63.1	61.1	66.4	25.0
22.0	48.9	53.4	52.2	51.8	51.2	50.1	51.0	51.0	24.8
23.0	49.3	55.1	55.0	54.5	51.5	55.1	52.6	56.9	25.3
24.0	47.7	54.0	52.5	52.4	49.7	52.6	50.5	53.6	27.7
25.0	50.0	56.6	57.6	57.4	53.7	57.4	55.3	65.8	29.5
26.0	56.1	60.5	66.3	63.8	61.1	67.1	63.6	80.7	31.0
27.0	54.7	59.8	62.6	60.0	58.9	60.8	60.6	62.7	31.7
28.0	51.3	57.6	56.6	56.4	53.9	54.4	54.9	56.9	32.5
29.0	52.8	59.1	59.5	59.8	55.9	60.5	57.6	66.6	33.0
30.0	54.7	60.5	62.1	61.0	58.1	61.8	59.8	66.0	30.9
31.0	56.0	61.9	64.0	62.4	60.4	60.5	61.4	67.6	28.6
32.0	55.3	61.4	62.2	62.1	57.9	61.9	59.3	69.3	28.6
33.0	55.6	61.5	62.6	60.3	58.5	60.1	59.6	61.2	29.0
34.0	54.1	61.1	60.5	60.6	56.8	57.3	57.6	62.4	28.0
35.0	54.2	61.2	60.6	60.6	56.3	59.7	57.4	62.2	27.0
36.0	56.6	62.9	65.1	64.4	60.4	65.4	61.7	72.7	26.6

VITAE

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List of Publication and Proceeding (If Possible)

Intararak, P., Dejchanchaiwong, R., Tekasakul, P., 2021. Optimization of operating parameters for rubber sheet fast drying in a forced-convection rubber smoking room. IOP Conf. Ser. Mater. Sci. Eng. 1163, 012010. https://doi.org/10.1088/1757-899X/1163/1/012010