Optimization of operating parameters for rubber sheet fast drying in a forced-convection rubber smoking room

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Abstract. A new design of a rubber smoking room for fast drying based on conventional rubber smoking room was tested. Effects of the operating parameters for the fast drying of rubber in a forced-convection rubber smoking room were investigated. Temperature distribution, moisture content, thermal efficiency, specific fuelwood, electricity and energy consumption were evaluated for drying of 1,500 rubber sheets. The suitable operating condition from the experiment is 60°C and 12 m/s for the temperature and velocity. The rubber sheet moisture content was reduced to 0.4% db within 36 hours, i.e. 36 hours less than conventional smoke drying. The variation temperature inside the rubber smoking room was near uniform with a maximum of 8.0°C. The temperatures ranges were 38.9-64.6°C at the front plane, 40.4-65.0°C at the middle plane, and 36.7-62.9°C at the rear plane. A new rubber smoking room can save up to 49.3% in fuelwood consumption as compared to conventional rubber smoking room. Hence, the new rubber smoke drying system is capable of enhancing thermal efficiency and saving energy compared to existing rubber smoking room.

1. Introduction

Natural rubber (NR) is an important agricultural product of Thailand. In 2016, Thailand produced more than 4.25 million tons of NR, accounting for 34.0% of global production. Most of them are exported in several forms. Ribbed smoked sheet (RSS) is one of the major products used in tire industry. The raw rubber sheets are dried in a smoking room where fuelwood is use as a heat source. Smoke from wood burning is also allowed to the smoking room to coat the rubber sheets as a means of product preservation before they are shipped to downstream industries.

Conventional natural-convective smoking rooms take at least 3 days (72 hours) to reduce moisture content (MC) about from 40% to 0.4%. In the drying room temperature is non-uniform and high specific energy consumption is about 1.26 kg/kg dried-rubber sheets [1-2]. Tekasakul and Promtong [2-4] have applied the computation fluid dynamics (CFD) technique to develop a more energy efficient RSS room. Size, position and numbers of gas supply ducts and ventilating lids were redesigned. Test results showed that the average temperature difference between any planes was is 4-7°C and modified RSS room was able to save 66.7% fuelwood consumption as compared to a
conventional RSS room with 15.7% thermal efficiency [5]. Dejchanhachaiwong, et al. (2017) developed a forced convection smoking room prototype and it could reduce drying time to 48 hours. Energy consumption was reduced by 55% compared to the convention smoking room. Temperature distribution inside the drying room was uniform with largest variation of about 6.75°C [1,5]. Maximum temperature variation in a typical convention smoking room is about 15.0°C. The reduction of the smoking time by 24 h give opportunity to manufactures mostly small business groups of local farmers or rubber cooperatives with daily production capacity of 1-3 metric tons [6]. However, large commercial smoking room with a capacity of 5-7 metric tons may require different design

In the present study, an inlet velocity of 12 m/s is used to compare with results from conventional natural-convective smoking room. Moisture content of fuelwood is about 60% dry. The objectives are to investigate the thermal performance and the unit cost. The RSS should meet the conditions for the class 3 standard [7].

2. Methodology

2.1. Rubber smoking room description
A fast drying rubber smoking room was constructed at the Saikao cooperative (N 7° 10’ 32” : E 100° 36’ 52”), located in the Muang District, Songkhla Province, Thailand. The room dimension is 5 m x 6 m x 2.5 m. A furnace generated heat and smoke supplied to the smoking room by forced convection. It has a dimension of 2.0 m x 2.1 m x 1.4 m and is connected to a 1.2 m diameter cylindrical tube and a blower (4,000 CFM). The flow rate of hot air was controlled by adjusting the speed of the blower motor using an inverter as shown Figure 1.

![Figure 1](image1.png)

Figure 1. A photo of the fast-drying rubber smoking room at Saikao rubber cooperative.

2.2. Methodology
Experiment was conducted for 1,500 rubber sheets. The rubber sheets in the present study were obtained from Saikao Cooperative. The thickness of rubber sheets was 3-4 mm which was controlled with the constant spacing of milling and followed the RSS standard [7]. Type-K thermocouples were used to measure temperature; 7 positions in the smoking room and 2 positions outside as shown Figure 2. Temperature was recorded by a data logger (Yokogawa, FX112-2-4). Velocity of air was measured at the inlet duct (V1) using a hot wire type anemometer (DIGICON DA-45S). The weight of three rubber sheet samples at Exam1, Exam2 and Exam3 positions in smoking room were measured by weight balance (Shimadzu ELB3000). Fuelwood was measured by a weighing scale (OHAUS Defender, TM 2000-E Series). Maximum temperature in the smoking room was maintained near 60°C. Average heating value of fuelwood used was 6.57 MJ/kg.
Figure 2. The positions of temperature, velocity and weight of rubber sheet samples measurement in the drying room.

3. Theory

3.1 Moisture content (MC)
Dry basis moisture content is preferable to measure the internal water of agricultural product. Initial moisture content of rubber sheets was about 40% and finalize moisture content was about 0.4%. It can be calculated from [2]

\[ \%Md = \frac{W_w}{W_d} \times 100 \quad (1) \]

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

3.2 Thermal efficiency and specific energy consumption.
Thermal efficiency and specific energy consumption are indicators for thermal performance of rubber smoking dryer. Thermal efficiency can be calculated from [2]

\[ \eta_{\text{dryer}} = \frac{m_L L}{(HV)_{\text{wood}} m_{\text{wood}} + E_e} \quad (2) \]

where \( m_L \) is the mass of water evaporated (kg), \( L \) is the latent heat of vaporization (kJ/kg), \( (HV)_{\text{wood}} \) is the heating value of the fuelwood (kJ/kg), \( m_{\text{wood}} \) is the total mass of fuelwood (kg), and \( E_e \) is the total electricity (kJ) [8].

Specific energy consumption (SEC) is the ratio between total supplied and amount of water removed. It can be calculated as [8]
\[ SEC = \frac{P_t}{W} \] (3)

where \( P_t \) is the total supplied energy to the RSS smoking room (kJ), and \( W \) is the mass of water evaporated (kg).

3.3 Cost of energy

Cost of energy takes into account of fuelwood and electricity costs. The unit cost of energy is defined as

\[ Cost = \left( \frac{m_{\text{wood}} \cdot m_c + (E_e \cdot E_c)}{m_{\text{total-dried-rubber}}} \right) \] (4)

where \( m_c \) is the price of fuelwood (current 0.7 baht/kg), \( E_e \) is the price of electricity per unit (current 3.7171 baht/unit), and \( m_{\text{total-dried-rubber}} \) is the total number of dried rubber sheets.

4. Results and discussion

4.1 Fast drying

The rubber sheets were dried after 36 hours. The temperature ranges were 47.4-64.7°C at the front plane, 52.6-67.5°C at the middle plane and 46.6-62.0°C at the rear plane, as shown in Figure 2. Temperature distribution in smoke room is uniform with largest variation of 6°C. Average temperature at front, middle, and rear plane is 58.2°C, 62.0°C and 56.0°C, respectively.

Moisture content of 3 rubber sheet samples at different locations is shown in Figure 3. It was reduced from initial MC of 40% to 0.4% in 36 hours. Drying rate in the first 6 hours is the fastest and it is slower until the process is over.

Total fuelwood consumption was 871.0 kg and electricity consumption were 110 kWh. The exhaust hot air recirculation was 0% from 0-6 hour, 50% from 6-24 hour, and 100% from 24-36 hour. Performance of the fast-drying rubber smoking room was evaluated. Thermal efficiency and SEC of fast-drying rubber smoking room are 20.5% and 10.8 MJ/kg of water evaporated, respectively. Details of performance are shown in Table 1. Physical appearance of the rubber sheets used in the experiment is shown in Figure 4. They passed the class 3 standard for RSS.
Figure 3. Temperature vs time at front, middle and rear plane.

Figure 4. MC during RSS drying in velocity 12 m/s.
Figure 5. Physical appearance of the rubber sheets used in the experiment.

Table 1. Overall performance of the fast rubber sheet drying.

| Item                      | value | unit         |
|---------------------------|-------|--------------|
| Good quality              | 1,361 | kg           |
| Good quality (%)          | 100.0 | %            |
| Drying time               | 36    | hour         |
| Fuelwood consumption      | 871.0 | kg           |
| Specific fuelwood consumption | 0.64   | kg/kg dried rubber |
| Specific Electricity consumption | 0.11   | kWh/kg dried rubber |
| Overall SEC               | 10.8  | MJ/kg of water evaporated |
| eff. dryer                | 20.5  | %            |

4.2 Comparison between conventional and fast-drying smoking room
Thermal efficiency of the fast drying is 20.5%, about 3 times improvement from the 6.9% of the conventional drying [1]. The specific energy consumption of the fast drying is 10.8 MJ/kg of water evaporated. It is improved from 34.4 MJ/kg of water evaporated for the conventional drying. Unit cost of rubber smoke sheet fast drying is 0.75 baht/dried rubber sheet (calculate at fuelwood price 0.7 baht/kg) in comparison to 0.90 baht/dried rubber sheet of the conventional smoking-room cost(4). Details of the performance comparison are shown in Table 2.
Table 2. Comparison between conventional rubber smoking room and fast drying smoking room

| Case            | Drying time (hour) | SEC (MJ/kg of water evaporated) | η drying (%) | Cost of RSS (baht/dried rubber sheet) |
|-----------------|--------------------|---------------------------------|--------------|--------------------------------------|
| Conventional    | 72                 | 34.3                            | 6.9          | 0.90                                 |
| Fast drying     | 36                 | 10.8                            | 20.5         | 0.75                                 |

5. Conclusion
A fast-drying rubber sheet smoking room is able to maintain a temperature near 60°C and uniform distribution with temperature deviation of 4-6 °C between planes. Moisture content of the rubber sheets is decreased from about 40% to 0.4% in 36 hours so that 36 hours of the conventional drying can be saved. Thermal efficiency of the fast smoking rooms increases from 6.9% to 20.5%. 13.6%, while the SEC is reduced from 34.3 to 10.8 MJ/kg of water evaporated. Cost in RSS production is reduced from 0.90 baht/dried rubber sheet to 0.75 baht/dried rubber sheet.

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