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Improvement of a rubber drying greenhouse with a parabolic cover and enhanced panels

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ABSTRACT

Two structures of a greenhouse for rubber drying: (1) parabolic greenhouse (PG) and (2) parabolic greenhouse with the additional area-enhanced panels (PGEP) have been designed and built in this work. The experiment was divided into two parts: (1) a test of the empty greenhouses; and (2) a test of the greenhouses with rubber sheets drying. The results from the first part revealed that the measured air temperature within the PGEP was 5 °C higher than PG's. The new-designed PGEP provides higher thermal efficiency than the PG. Mathematical model was utilized to predict the air temperatures inside the empty greenhouses and the results agreed well with the experimental data. In addition, the test of greenhouses with rubber sheets drying showed that the drying period in PGEP was only 1.5 days while the drying period in PG was up to 5 days. The rubber sheets dried with this method were classified as grade 1 (the top quality) and there was no fungal growth found in the sheets. The finite difference was applied in the mathematical model to predict the reduction of moisture content of the rubber sheets. The results from the model agreed well with the results from the experiments. Other significant parameters were also discussed.

1. Introduction

According to the world rubber industry reports in 2011, Thailand's production and export of natural rubber products were one third of the total natural rubber production in the world. Rubber industry is divided into two categories—natural rubber industry and rubber production industry. Rubber sheet drying, which is one of the most important natural rubber industry, can be divided into two types, according to the processes of drying [1]: Air Dried Sheet (ADS), which is the method of drying rubber sheet with 45–65 °C hot air, and Ribbed Smoked Sheet (RSS), which is the traditional process of smoking fresh rubber sheet at 50–60 °C. RSS generally utilizes the heat from burning rubber tree firewood in a special designed furnace and the amount of the heat inside the smoking chamber is controlled by the quantity of the firewood in order to maintain the suitable heat for rubber sheet drying. By this method, not only the heat from the furnace dries rubber sheet quickly, but the smoke from the burning process also prevents fungal growth. However, firewood burning harms the environment due to the excessive heat and CO_2 emission. Furthermore, inexperienced operation may cause heat controlling problem which results in rubber sheet quality, for instance, bubbles in rubber sheet because of too high temperature, and slower dried of rubber sheet due to too low temperature which also leads to fungal growth on the sheet during drying process. This traditional drying method also wastes a lot of heat on drying process.

According to the survey of rubber sheet smoking factories [2,3] in the southern part of Thailand, the quantity of rubber tree firewood used to smoke rubber sheets each year is approximately 229,994 m^3 or 1.38×10^5 kg (1 m^3 of firewood = 600 kg). In other words, this amount of firewood can generate heat to dry rubber sheets at 2.14×10^6 GJ. Therefore, the more energy consumption decreases, the more cost reduces. The survey also showed that the efficiency of the traditional drying chamber is obviously low since the heat from burning process is used only 31%, the rest is wasted via the chamber walls 57% and flows into the atmosphere.

As a result, greenhouse drying is the appropriate and environment-friendly method that uses the clean solar energy. As reported by the study of greenhouse designs, there are a variety of greenhouses such as the tunnel greenhouse of Condori and Saravia [4–6]. The main part of the greenhouse was covered by plastic sheets. The study was divided into two systems: a single chamber greenhouse; and a twin chamber greenhouse. The result showed

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Nomenclature

A_f	Area of the floor (m^2)
A_g	Surface of the greenhouse floor (m^2)
A_i	Area of the cover (m^2)
a_w	Water activity
C_p	Air specific heat (kJ/kg °C)
D	The average distance from the floor to the cover of the greenhouse dryer (m)
D_{eff}	The moisture diffusion coefficient of rubber sheet (m^2/s)
D_h	A hydraulic diameter (m)
D_o	The pre-exponential factor of the Arrhenius equation (m/s^2)
E_a	The activation energy (kJ/mol)
F_n	Fraction of the sun ray on north wall
$h_{c,c-r}$	Convective heat transfer coefficient from the cover to the air inside the greenhouse (W/m^2 °C)
$h_{c,g-r}$	Convective heat transfer coefficient from the concrete floor to the air inside the greenhouse (W/m^2 °C)
h_{fg}	Latent heat of vaporization (kJ/kg)
$h_{g\infty}$	Conduction heat transfer coefficient from the greenhouse floor to underground (W/m^2 °C)
h_m	The convective mass transfer coefficient between rubber sheet and surrounding (m/s)
I_i	Solar intensity on the greenhouse wall/roof (W/m^2)
k_a	Conductivity of the air (W/mK)
k_f	The conductivity of the floor (W/m K)
L	The distance from the center of the thickness of rubber sheet (m)
L_f	The thickness of the floor (m)
$\dot{m}$	Air mass flow rate (kg/s)
$\bar{M}$	The average of moisture content (decimal dry basis)
M_{db}	Moisture content dry basis
M_{eq}	The moisture equilibrium of rubber sheet (decimal dry basis)
M_i	The initial moisture content (decimal dry basis)
MR	The moisture ratio of rubber sheet
M_s	The moisture content at rubber sheet surface (decimal dry basis)
m_w	Mass flow rate each day (kg/s)
N	Number of the air changes per hour
R	The universal gas constant (kJ/mol K)
Re	The Reynolds number
T	The drying temperature (K)
T_a	Ambient temperature (°C)
$T_f\|_{x=0}$	Temperature on surface of the floor of the greenhouse (°C)
T_i	Temperature inlet of the greenhouse (°C)
T_o	Temperature outlet of the greenhouse (°C)
T_r	Temperature inside the greenhouse (°C)
T_∞	Average temperature under the ground (°C)
U_i	Over all heat loss (W/m^2 °C)
V	Volume of the greenhouse (m^3)
V	The volume of particle (m^3)
v	Velocity of the wind (m/s)
V_a	Velocity of the air inside the greenhouse dryer (m/s)
W	The width of the greenhouse dryer (m)
W_d	Dry weight of product (kg)
W_o	Wet weight of product (kg)
x_o	The center position of the thickness of rubber sheet

Greek letter

α_g	Absorptivity of the greenhouse floor
η_{drying}	Thermal efficiency of dryer (%)
η_{empty}	Thermal efficiency of the empty greenhouse (%)
ρ	Reflection of the cover
ρ_a	Density of the air (kg/m^3)
τ_c	Transmissivity of the cover
υ	Viscosity of the air

that the twin chamber greenhouse is better in terms of the technical efficiency. Kurlu et al. [7] designed a tunnel greenhouse. In the system, rock bed was built underneath the greenhouse to store heat during the daytime. In the night time, it was found that the inside temperature of the greenhouse was 10 °C higher than the outside temperature. The efficiency of this greenhouse was 34%. Kumar and Tiwari [8] studied the effect of mass on convective mass transfer coefficient between open sun and greenhouse drying of onion flakes. For greenhouse drying, the result showed that convective heat transfer coefficient depended on mass of onion flakes and drying methods. It was also found that greenhouse drying method provided higher heat transfer coefficient. Janjai et al. [9–12] developed solar drying greenhouse cladding with polycarbonate sheets. The greenhouse was built in parabolic shape and electric fans were installed to ventilate the moist air from the greenhouse. Concrete base of the greenhouse functioned as an absorber.

At present, the study of rubber sheet drying in Thailand and many countries in Asia, especially greenhouse drying, is not abundantly developed. In addition, most of them focused on varieties of supplementory energies which are practically complicated for the local farmers as well as waste of some energy to the environment. Kalasee [13], for example, designed a new way to develop a simple rubber sheets smoking. The heat diffuser was installed over the hot gas inlet of the smoking room. In this case, the average thermal efficiency rose up to 29.1%. The amount of firewood used for rubber smoking was 653 kg per a ton of smoked rubber sheets. The number of firewood decreased 45%, compared to the traditional smoking method. Beymayer et al. [14] introduced the solar air heater to the rubber sheet smoking system. It was found that the drying rate was better in which the normal smoking took 12 days, but with solar air heater it took only 5–6 days. Nilchuewong et al. [15] studied rubber sheet drying with hot air and greenhouse drying, and the result showed that drying rate of hot air drying was better. However, the energy consumption of hot air drying was ranged 8–20 MJ/kg of water evaporation. The quality of the rubber sheets from both experiment conditions were passed the local market criteria (Grade 1–3) and the yellowness of dried rubber sheets proportionally varied to drying temperatures. Tanwanichkul et al. [16] designed Sandwich Greenhouse to dry rubber sheets. In this drying system, a drying chamber is coupled with two heating rooms. The temperatures inside the drying chamber ranged from 29 to 49 °C, which were 5 °C higher than the ambient temperature, in both the daytime and the night.

In consequence, this research has been carried out to develop the appropriate greenhouse design for rubber sheet drying by investigating thermal efficiency of the newly designed parabolic greenhouse with additional solar collecting panels (PGEP). In this study, the supplementary solar collecting panels are specially designed to install on the left and right sides of the prototype parabolic greenhouse to enhance the solar collecting area. The thermal efficiency of PGEP is compared to the opponent collected from the parabolic greenhouse (PG) which is originally designed by Jan-