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Assessment of sensible heat storage and fuel utilization efficiency enhancement in rubber sheet drying

Perapong Tekasakul*, Anil Kumar, Chalad Yuenyao, Pairoj Kirirat, Gumpon Prateepchaikul

Energy Technology Research Center and Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla, 90110, Thailand

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ABSTRACT

A sensible heat storage unit was tested in the conventional method of rubber drying. The heat storage unit gradually releases the heat to the rubber sheet smoke room. This retains temperature in the range (40–60 °C) for prolonging storage in the smoke room. Therefore, the frequent supply of wood to the furnace is trimmed down. Effects of the heat storage brick stack height on heat storage characteristics and applications for rubber sheet drying were investigated. The experiments were conducted at three heat storage heights, 50, 100, and 150 cm. For all cases, the temperature of the brick stack was found to increase sharply during the initial period and remained constant for a period of time before slowly declining. This is a result of the heat storage system that maintains the high temperature by slightly releasing the generated heat. Thermal efficiencies of heat storage system varied between 33 and 28% for the heights of 50 to 150 cm. The drying time of the rubber sheets using 100 cm heat storage was 78 h, while the thermal efficiency of the drying system was 6.71%. The frequency of wood addition was reduced from about five to six times per day to one time or less per day.

1. Introduction

Natural rubber is an important plant (*Hevea brasiliensis*) that yields a product used extensively in industry, including automotive tires, medical equipment, glove manufacturing, and condom manufacturing. About one-third of natural rubber is produced in the form of ribbed smoked sheets (RSSs) before being used by the downstream industries [1]. Generally, RSSs are dried by the rubber smoking process with direct heat from wood combustion. During this process, fresh rubber sheets are produced from squeezing coagulated rubber slabs and dried in rubber sheet smoke rooms in a smokehouse using old rubber wood or firewood as a source of heat and smoke [2]. The smoke house is constructed from brick and mortar with furnaces on its back side. The drying time can be more than 140 h with average temperatures under 60 °C for fresh rubber sheets initially containing about 40% water (dry basis). 0.8–1.2 tons of fuel is used for each ton of dried RSS [3].

The firewood consumption rate is high because the heat is used directly and combustion is difficult to control. The major part of the heat is discarded through a chimney without being used, which results in low fuel efficiency. Once, the wood is loaded in the furnace, it is difficult to control the combustion [4]. Hence, it is desirable to find an effective method for storage of the excess heat in order to use it steadily and efficiently. Implementation of a heat storage system can maintain the optimum temperature for longer-reducing the frequency of wood supply. The advantages of attaching this unit in the rubber drying process are; to reduce direct heat-loss through the chimney, avoid high temperature during combustion and to continue transferring heat even when the combustion of firewood ends.

For a thermal energy storage unit, heat is stored in a suitable medium and extracted at the desired rate. It may be in the form of a sensible heat or latent heat storage. Ability to store heat depends on the specific heat of each medium. Media that are widely used for heat storage are listed in the literature [5–9]. Factors influencing the choice of the storage medium for the rubber sheet smoking include price, availability, ease of use and durability and high density and specific heat capacity [10]. A latent heat storage unit is generally smaller than a sensible heat storage unit but the design and media selection are more complicated. Moreover, experience with low-temperature salts shows that the materials performance

* Corresponding author.
E-mail address: perapong.t@psu.ac.th (P. Tekasakul).

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degrades after a moderate number of freeze-melt cycles. Phase change material (PCM) has inherent problems such as contamination and imperfect re-solidification [11]. Furthermore, sensible heat storage is relatively inexpensive and more suitable for an air-based system [12].

Water is the most efficient medium for storing heat per volume because it is readily available and lower in price. It is in a liquid phase at the temperature range of 0–100 °C at an atmospheric pressure, which is a limit of using the sensible heat system. On the other hand, concrete, rock and brick although having lower heat storage per volume are also easy to handle and very durable [13].

Sensible heat media requires a large volume to store the equivalent quantity of heat energy but here, it is not a major concern because rubber factories are situated in remote areas where space is not a concern. Brick – bed storage has a major advantage as it is not necessary to change the heat transfer medium. Heated air from the brick bed can directly pass into the drying chambers. Hence, a brick bed was selected as the storage medium.

In this study, integration of sensible heat energy storage system into a smoke room for natural rubber drying was attempted. Heat was stored in the unit during the combustion and it was slowly released to the smoke room, for a significant period after combustion ended. The main objectives were: to study the heat storage characteristics for the different capacity of brick bed, fuel efficiency enhancement in ribbed smoked rubber drying and a performance test of rubber sheet smoking in a smoke chamber.

2. Heat storage characterization method

The thermal efficiency (η_{th}) is the ratio of the total heat discharge from the system (heat stored in brick based sensible heat storage and direct heat from fuel combustion) to the heat contents of wood consumed in the furnace. It accounts for the energy loss during the storage and discharge period. It can be calculated from:

$$\eta_{th} = \frac{Q_{tr}}{m_{wood}(HV)_{wood}} \times 100\% \quad (1)$$

where Q_{th} is the heat discharge from the system, m_{wood} is the total mass of consumed firewood and $(HV)_{wood}$ is the wood heating value depending upon its moisture content [14]. The firewood moisture content was measured by drying wood samples in an electric furnace between 110 and 120 °C until there is no change in mass. Moisture content of firewood (dry basis) can be determined from:

$$MC_{DB}(\%) = \frac{m_i - m_d}{m_d} \times 100\% \quad (2)$$

where m_i is the mass of fresh firewood before drying and m_d is the mass of completely dried firewood [14].

Heat discharge can be measured by using a heat exchanger to receive all of the heat transferred from the storage. This can be calculated from:

$$Q_{tr} = m_w c_{p,w} \Delta T_W \quad (3)$$

where m_w is the total mass of water flowing through the heat exchanger, $c_{p,w}$ is the specific heat capacity of water used as a medium in the heat exchanger and ΔT_W is the difference between the inlet and outlet water temperatures in the heat exchanger [14].

3. Experimental set up and procedure

Fig. 1 shows the components used in the experimental setup to evaluate the heat generation rate from the combustion of firewood and the heat storage system include: a furnace, a sensible heat storage unit and a heat exchanger. Details of each part follow.

3.1. Heat storage system

Old rubber-wood was burnt in the furnace. The combustion gas flew through a stack of construction bricks used as heat storage and left the system via a small opening on the top surface.

All surfaces of the system were sufficiently insulated to minimize the heat loss to the environment and therefore neglected. Heat produced was transferred to the heat exchanger to measure the fuel utilization efficiency. The heat exchanger received heat from the storage by natural convection and conduction heat transfer modes.

The air surrounding the heat source and storage media receives heat, becomes less dense, rises and exits. The surrounding cooler air then moves to replace it. This cooler air is then heated and the process continues, forming a convection current, driven by density differences between inlet and outlet. This process transfers heat energy from the heat source and storage media.

The convective air flows through porous spaces in the storage system. Conduction through the stack of bricks retards the heat

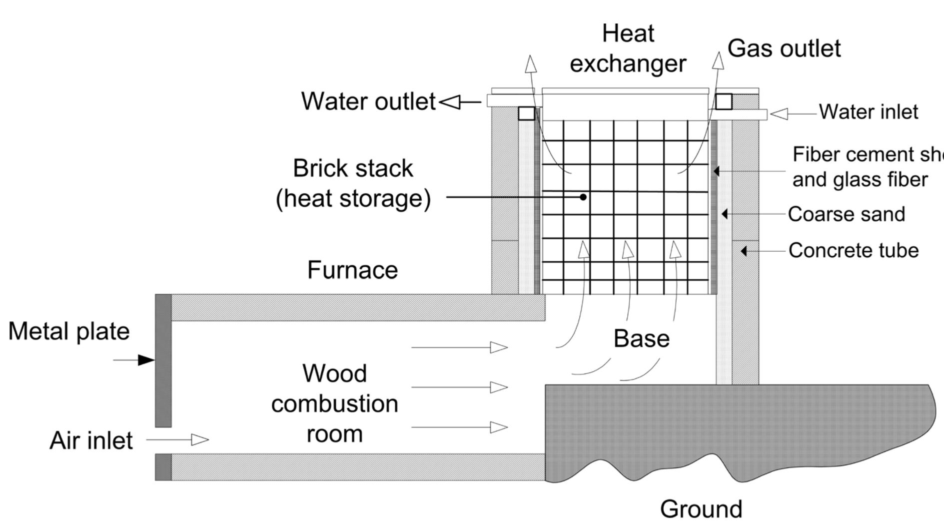

Fig. 1. Experimental setup for heat storage characterization.