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Drying kinetics of technical specified rubber

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ABSTRACT

This paper reports the study of crumb rubber drying in different experimental designs. It is important to understand the characteristics of crumb rubber drying in order to formulate a better drying strategy that could give higher energy efficiency. Four experiments were carried out with constant heat at maximum 100 °C and a stainless steel container was used to hold the sample of crumb rubber under study. The surface temperature profile of the rubber was investigated using two types of drying methods, normal hot air drying and vacuum drying. It was found that when the sample was dried, external surface temperature for drying with hot air dryer was higher than vacuum dryer. The results showed the evolution of temperature profile was not in good agreement with the prediction which revealed that there was no temperature gradient within the drying samples. The energy consumption for vacuum drying was higher compared to hot air drying, where there was a difference of 0.7079 MJ/kg H_2O evaporated for drying temperature at 100 °C. The best fit model generated from the experimental data was the modified Henderson and Pabis model and the highest effective diffusivity obtained was 5.243×10^{-9} m^2/s heating by vacuum oven at 90 °C under zero atmospheric pressure.

1. Introduction

Since early twentieth century, rubber has been an important commodity for Malaysia [1]. The success in rubber planting and the fast development of automobile industries have made Malaysia one of the leading rubber exporters. Rubber latex is the sap, a protective layer beneath the bark of rubber tree (Hevea brasiliensis), which is normally tapped from the bark of *Hevea Brasiliensis tree,* is also named as polyisoprene. This rubber tree originated from Brazil and its seedlings were then exported to Sri Lanka, Singapore and other Asia countries, including Malaysia [2]. The early use of rubber was restricted to waterproof shoes, it was then further popularized when Charles Goodyear vulcanized the rubber into modified rubber [3].

The current main rubber products for medical industries, baby care and automotive industries are commonly produced from concentrated latex or solid rubber. Both types of rubber have to be further processed once the sap was tapped from tree. The centrifugation of field latex will be able to produce concentrated latex in liquid form with dry rubber content (DRC) of 60% and above [4]; while rubber sheet or crumb rubber is a type of dry rubber products that is rather important for tyre industries. The raw rubber that was required for tyre manufacturing process, known as crumb rubber, is commonly marketed in various grade and wrapped with polyethylene plastic sheets [5]. Crumb rubber is also known as "technical specified rubber" [6], where 70% are sold to tyre industries [7].

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In this paper, the drying of technical specified rubber (TSR) was investigated. In TSR, the initial plasticity, plasticity retention index and volatile matter are very important. For related rubber products like gloves, the mechanical strength, including tensile strength, elasticity, and modulus are part of the crucial test to validate product quality. The rubber product's properties usually remain unchanged at normal room temperature, but the strength, elasticity and flexibility of rubber deteriorate faster when stored in hot condition. Generally, crumb rubber was graded according to Standard Malaysia Rubber (SMR), where the requirement was as mentioned in Table 1.

Crumb rubber drying process is important in minimizing the moisture content in rubber, reduction of water activity, and to ensure consistent end product quality. Researches by Kulchanat [8] and Yodthong [9] have shown that the addition of wood vinegar to the drying process able to reduce bacteria growth and inhibits anti-fungal properties on rubber. Thus, the main objective of this study is to understand the drying kinetic of crumb rubber and changes of temperature profile on rubber surface when drying under hot air. The current rubber drying requires drying air temperature in the range of 130 °C and heating continuously up to three hours, but the process carries a possibility of inconsistent product quality with high energy consumption. The most popular artificial drying is the use of trolley dryer by hot air convective drying method. However, the skyrocketing fuel cost is one of the main challenges to current rubber processing plants. There are limited researches on rubber drying process. Berthomieu [10], Khongchana [11], Yutthana [12] and Suchonpanit [13] works have shown some similarities in trying to simulate and design industrial dryers. According to Khongchana [11], the specific energy consumption is measured by the equation below:

$$SEC = \frac{2.6(\sum W_M) + (\sum Q_h)\Delta t}{W_w} \quad (1)$$

where

SEC = Specific energy consumption, MJ/kg water evaporated;
Q_h = Heat energy consumption, kW;
W_M = Electrical energy consumption, kW;
W_W = Weight of water evaporated out from the rubber, kg.

However, there are multiple differences in Jutarut's [14] equation to measure the specific energy consumption:

$$SEC = \frac{2.6(\sum E_{fan}) - (\sum Q_h)\Delta t}{M_w} \quad (2)$$

Where

SEC = Specific energy consumption, MJ/kg water evaporated;
Q_h = Rate of Heat energy consumption, kW;
E_{fan} = Rate of Electrical energy consumption of fan, kW;
M_W = Weight of water evaporated out from the rubber, kg.

The calculation presented by Jutarut involved the rate of electrical energy and heat energy consumption. From the two equations mentioned, we can see obvious differences in both, whereby one was calculated based on the addition of heat energy and electrical energy, and other SEC was using subtraction of heat energy for calculation. The differences in calculation methods may lead to difficulties to compare the SEC values from different researchers. Therefore, there is a need to investigate the actual energy consumption in similar drying system. Besides evaluation of drying kinetic and specific energy consumption (SEC) of rubber drying process, a total of eleven types of mathematical models were analyzed to determine whether the drying technique was suitable for industrial scale rubber processing.

2. Materials and methods

2.1. *Raw materials and equipment*

Fresh crumb rubber (Lien Rubber (M) Sdn. Bhd., Port Klang, Malaysia) was acquired from a local natural rubber processing company. The crumb rubber was coagulated and washed prior to purchase; however, further removal of dirt was necessary for higher accuracy of test. The rubber size was reduced by creper shredder machine and the appearance was similar to a long thread with diameter of 4 mm ± 1 mm. The rubber would entangle and stick to each other upon heat treatment. Therefore, proper selection of rubber, washed off surface adhering dirt, and size are important for the accuracy of drying test.

The drying of rubber was carried out by two types of dryers, universal lab oven (Memmert, UFB 500, Germany, Evergreen Engineering & Resources) and vacuum oven (Tuff, TVAC-92, Germany, Tech-Lab Scientific Sdn Bhd) with the use of a stainless steel container 150 mm × 75 mm × 75 mm made by Sphere Corporation. A schematic diagram (see Fig. 1) showed how the rubber sample was placed into the container. The universal oven employed hot air (HA) drying method by natural convection, with a heater of 1600watt and temperature accuracy of ±0.1 °C; while the vacuum dryer employed vacuum drying (VD), which consisted of a build in

Table 1 – Technical specification for Standard Malaysia Rubber (SMR).

Parameter	SMR 10	SMR 20
Dirt Retained on 44 Aperture (Max, % wt)	0.08	0.16
Ash Content (Max, % wt)	0.75	1.00
Volatile Matter (Max, % wt)	0.80	0.80
Nitrogen Content (Max, % wt)	0.60	0.60
Wallace rapid plasticity, P_O (Min, %)	30	30
Plasticity retention index, PRI (Min, %)	50	40