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Study on effectiveness of continuous solar dryer integrated with desiccant thermal storage for drying cocoa beans

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ABSTRACT

The main objective is to assess effectiveness of continuous solar dryer integrated with desiccant thermal storage for drying cocoa beans. Two type of desiccants were tested, molecular sieve 13× ($Na86\ [(AlO_2)86\cdot(SiO_2)106]\cdot 264H_2O$) as an adsorbent type and $CaCl_2$ as an absorbent type. The results revealed that during sunshine hours, the maximum temperature within the drying chamber varied from 40 °C to 54 °C. In average, it was 9–12 °C higher than ambient temperature. These temperatures are very suitable for drying cocoa beans. During off-sunshine hours, humidity of air inside the drying chamber was lower than ambient because of the desiccant thermal storage. Drying times for intermittent directs sun drying, solar dryer integrated with adsorbent, and solar dryer integrated with absorbent were 55 h, 41 h, and 30 h, respectively. Specific energy consumptions for direct sun drying, solar dryer integrated with adsorbent, and solar dryer integrated with absorber were 60.4 MJ/kg moist, 18.94 MJ/kg moist, and 13.29 MJ/kg moist, respectively. The main conclusion can be drawn here is that a solar dryer integrated with desiccant thermal storage makes drying using solar energy more effective in term of drying time and specific energy consumption.

1. Introduction

Cocoa beans (*Theobroma cacao*) are one of the leading commodities of Indonesian plantation, along with rubber and crude palm oil. In 2011–2012, Indonesia produced 440 Mt of cacao beans. This makes Indonesia one of the biggest cacao beans producers after Ivory Coast and Ghana [1]. Smallholder farmers produce almost 95% of Indonesian cocoa beans. Since the postharvest is processed traditionally, the Indonesian cacao bean is known with poor quality production. This is the main drawback of Indonesian cocoa beans and it can lower the price in international market. In order to overcome the weakness, the Government of Indonesia has been releasing a national movement on improvement of production and quality of cocoa beans since 2009.

Fermentation and drying are two main steps in the postharvest processing of cocoa beans. These steps play an important role in the formation of flavor and taste. These steps should be treated properly in order to improve the quality of cocoa beans. The main objective of drying is to reduce the moisture content of cocoa beans to moisture content less than 10%.

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However, drying method can improve the quality of dried cocoa beans. Many researchers have reported study on the effects of drying method to the cocoa beans quality. Jinap et al. [2] studied several different types of drying conditions evaluating the acidity and volatile fatty acids and concluded that cocoa beans dried in an oven at 60 °C retain a high content of acetic, propionic, butyric, isobutyric, and isovaleric acids, which helps in the making of a low quality chocolate. Camu et al. [3] showed that during drying of cocoa beans, strong browning reactions occur that include oxidation of pholyphenols with reduction of astringent and bitter taste. When the drying is slow, non-volatile lactic acid may partly be transported by the water from the bean to the husk. Polyphenols and polyphenols oxidase are sensitive to the drying process. Bonaparte et al. [4] have reported a study on field comparison of solar drying and open-air sun-drying cocoa beans. The results showed that the cocoa beans from indirect dryer showed the highest quality and those from the direct sun drying the poorest. Hii et al. [5] carried out a study to compare the quality characteristics of cocoa beans dried using solar dryer (indirect type) and sun dryer (direct type) with perforated and non-perforated platforms. Results showed that solar drying can be used as an alternative to sun drying with a better quality.

Many designs of solar dryer for drying agricultural products can be found in literature [6]. The good design of solar dryer can result in a hot drying air in order of 10–25 °C above the ambient temperature. However, solar dryer which uses solar energy as energy resource has two main weaknesses. It is intermittent by its nature and is dependent on the the weather conditions of the location. In the nighttime, when the sunshine is off, ambient temperature decreases, while the relative humidity increases. In some cases, the dried object will re-absorb the moisture. This will make the drying time longer and the worst case, it can ruin the dried object because of mold [7]. To avoid or to reduce the intermittent effects, some researchers proposed solar dryer integrated with a thermal energy storage material to store excess heat in the daytime and uses it in the nightime [8].

The excess thermal energy can be stored in well-insulated fluids or solid in internal energy of material as sensible heat, latent heat and thermo-chemical or combination of these [9]. Some researchers have reported their study on the thermal storage material for drying foods and agricultural products. Buttler and Troeger [10] have experimentally evaluated a solar collector-cum-rockbed storage system for peanut drying. Devahastin and Pitaksuriyarat [11] investigated the feasibility of using latent heat storage with paraffin wax as a phase change material to store excess solar energy during drying and release it when the energy availability is inadequate or not available. The effect on drying kinetics of a food products (sweet potato) was explored. Shanmugam and Natarajan [12] have reported study on the performance of an indirect forced convection and desiccant integrated solar dryer for drying of green peas and pineapple slices. The system is operated in two modes, sunshine hours and off-sunshine hours.

The aforementioned studies showed that, solar dryer is the best method for drying cocoa beans in comparison with conventional direct sun drying and artificial drying. However, its intermittent is the main weakness. Thermal energy storage can be used to avoid the intermittent effect. To the best knowledge of the authors, study on drying cocoa beans using a solar dryer integrated with thermal energy storage has not been reported. This paper deals with solar dryer integrated with thermal energy storage for drying of cocoa beans. The main objective is to study the effectiveness of continuous solar dryer integrated with thermal energy storage in term of drying time and specific energy consumption. The results are expected to provide the necessary informations in order to support the Government of Indonesia movement on improving the quality of Indonesian cacao.

2. Materials and methods

2.1. Sample preparation

Cocoa fruits were collected from Deli Serdang regency of Sumatera Utara province of Indonesia. Before drying, the fresh cocoa beans were fermented using boxes made of Styrofoam for five days. The fermentation methods have been reported elsewhere [13]. The cocoa beans for one batch of drying was 1 kg with initial moist content varies from 59.15% to 60.37%. This is a typical initial moist content for fermented cocoa beans in Indonesia.

2.2. Solar dryer and drying method

A prototype solar dryer has been fabricated and used in experiments. The solar dryer is shown in Fig. 1(a). It consists of three main components: drying chamber; solar collector; and thermal energy storage. The drying chamber is a room with dimension of 50 cm × 50 cm × 50 cm. The dried cocoa beans were spread in a drying tray made of perforated aluminum sheet with an area of 49 cm × 49 cm. Thermal storage was placed in an open container made of steel with dimension of 30 cm × 30 cm × 5 cm. Picture of the drying tray, cocoa beans and the thermal storage are shown in Fig. 1(b). The solar collector is a flat plate type with dimension of 2 m × 0.5 m × 0.1 m. The absorber was black-painted made of 1 mm galvanized steel sheet. Two plain window glasses separated by a 2 cm air gap were used as transparent covers to prevent the heat loss from the top. The solar collector was oriented Northward with a tilt angle of 60°. Fig. 1(c) shows detailed cross section and thermal resistant analogy of the solar collector envelope.

As a note, drying is a simultaneous heat and mass transfer process and is followed by evaporation. The drying process can be driven by temperature difference and/or concentration difference. A lower vapor concentration of drying air above the surface can provide drying process, even though the temperature of the object is relatively low. In order to make drying process occur even if the temperature is low, the thermal storage material proposed in this study was desiccant and it can be recycled using heat from solar energy. The desiccant will be categorized as thermo-chemical energy storage. Two type of desiccant, $CaCl_2$ and molecular sieve 13× (Na_{86} [$(AlO_2)_{86}\cdot(SiO_2)_{106}$]$\cdot 264H_2O$), were tested. Based on the working mechanism, each desiccant will be categorized differently, $CaCl_2$ as absorbent type and molecular sieve 13× as adsorbent type.

The solar dryer was operated in two drying modes, daytime and nighttime. In the daytime, the cocoa beans is dried inside the drying chamber by using hot air resulted by the solar collector. In the same time, the thermal storage is heated using direct solar energy in order to store the heat and to release the