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Experimental Study on a Solar Tunnel Heat Pump Dryer for Cocoa Beans

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Abstract

A solar tunnel heat pump dryer was designed, constructed and tested for drying cocoa beans. The dryer consists of heat pump, single pass flat plate solar collector with fin, drying tunnel, turbine ventilator and blower. As much as 48 kg of cocoa beans with the moisture content of 67% wet basis was reduced the moisture content to 8.6% wet basis needed 20 hours whereas the moisture content of cocoa beans was reduced to 26 % wet basis using open sun drying in the same period. The minimum and maximum of the drying rate and the thermal efficiency of dryer were estimated of about 0.12 kg/h and 2.91 kg/h, 4.39% and 37.79%, and in average are 1.31 kg/h and 19.87%, respectively. The drying of cocoa beans have two drying periods, namely, the constant drying rate period and the falling rate period. Result shows that this dryer is capable of drying cocoa beans quickly because of the high drying rate. Also, the quality of cocoa beans in term of colour is using dryer were better than using open sun drying, because the short drying time, the products have no contamination of dust, dirt and other pollutants.

Keywords: Drying, Heat pump, Solar tunnel dryer, Performance, Cocoa beans

1 Introduction

Indonesia, a tropical country, is the third largest producer of cocoa beans in the world after Ivory Coast and Ghana with the production 720,862 tons and export 414,092 ton in year 2013 [1]. Cocoa is the main source of income for over 400,000 the smallholder farmers and their families in Indonesia [2]. The smallholder farmers contribute 90% of the national production, the remainder comes from state owned plantations and private estates. However, the Indonesian cocoa beans have low competitiveness compared to both countries because the dried cocoa beans are low or poor quality. One of the causes of low or poor quality of dried cocoa beans is because the smallholder farmers, the cocoa beans are dried by open sun drying. In the open sun drying, the products are spread on the concrete floor and are raised platform which are contaminated by dust, dirt and other pollutants, thereby, degrading the quality of the products. The quality the products will further be degraded by the delays drying when a rainy day or long drying time and the moisture content of drying products are not uniform, which causes the mould growth. Solar dryer is an alternative to solve this problem, and one of them is a solar tunnel dryer.

Solar tunnel dryers have been used to dry agricultural products such as paddy [3], green chilies [4], limes [5], tomato [6], chilly [7], andrographis paniculata [8], copra [9], grapes [10], di-basic calcium phosphate [11], hot chilli [12], chilli [13], jack fruit and jack fruit leather [14], red chilies [15], Fish [16], pineapple [17], banana [18], fruits [19]. The researchers found that the low drying rate and long drying time when low sunligh and cloudy day, and also the drying process cannot be conducted during rainy day. Therefore, it is necessary to provide the solar tunnel dryers with an auxiliary dryer, such as heat pump. The objective of this paper is to design and to experimentally study of performance of a solar tunnel heat pump dryer for drying cocoa beans.

2 Experimental set up

A solar tunnel heat pump dryer was designed and installed at the Institute of Technology Padang, West Sumatra, Indonesia. The drying system consists of heat pump, single pass flat plate solar collector with fin, drying tunnel, turbine ventilator and blower shown in Fig. 1 and 2. The heat pump consists of several main parts: evaporator, condenser, compressor and expansion valve. The working fluid of the heat pump is R-22. The compressor uses of electrical capacity of 0.373 kW. The dryer wide of 120 cm, with a solar collector length of 125 cm and a drying tunnel lenght of 400 cm. The drying tunnel consists of four parts, namely the drying tunnel first (dt1), second (dt2), third (dt3), and fourth (dt4), with each length is 100 cm. The drying air is circulated by using blower with electrical capacity 0.373 kW. The turbine ventilator is used to suck moist air in the drying tunnel.

3 Experimental procedure

The experiments were carried out at Padang Institute of Technology, West Sumatra, Indonesia. As much as 48 kg fermented cocoa beans were placed into the drying tunnel for the drying process shown in Fig. 3. The air temperatures entering and leaving the heat pump, solar collector and the drying tunnel were measured by using T-type thermocouples with an accuracy of ± 0.1^{o}C. The solar radiation was measured by an LJ-200 pyranometer with an accuracy of 0.1Wm^{-2}.

The air velocity was measured with 0-30 ms^{-1} range an HT-383 anemometer, an accuracy of ± 0.2 ms^{-}1. The air temperature and the solar radiation were recorded by an AH4000 data logger with accuracy of ± 0.1°C. The weight changes of the cocoa beans were measured by 0-15 kg range a TKB-0.15 weighing scale, an accuracy ± 0.05kg. Cocoa beans were weighed and temperature was measured every 60 minutes, respectively.

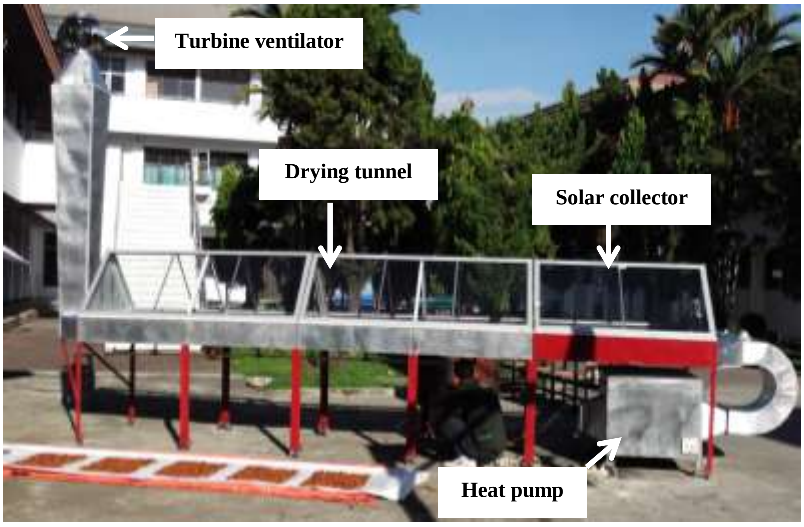

Fig.1. Photograph of the solar tunnel heat pump dryer

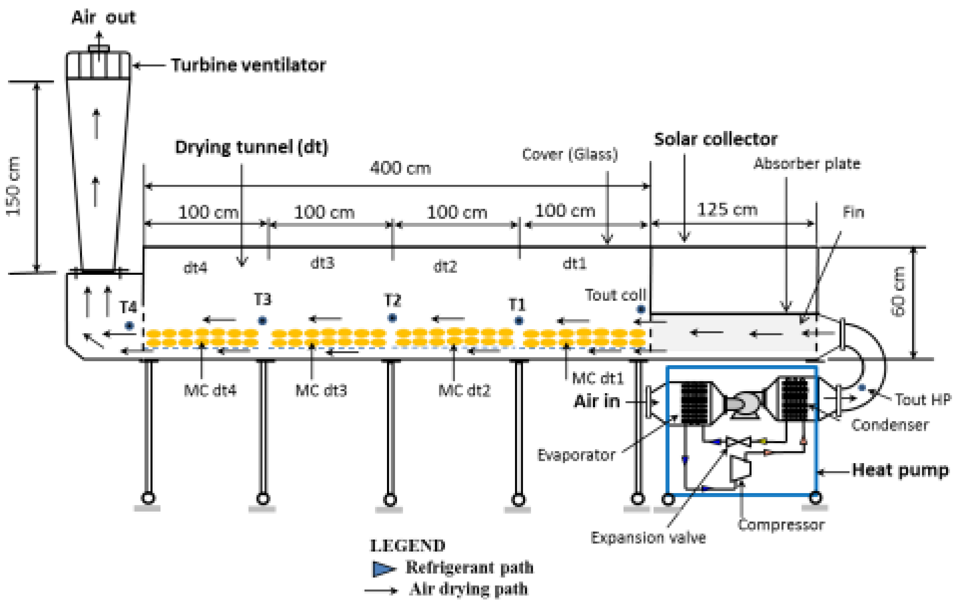

Fig.2. Schematic diagram of the solar tunnel heat pump dryer

- Tout HP is out let air temperatur of heat pump.
- Tout coll is out let air temperatur of solar collector.
- T1, T2, T3, and T4 are the temperature of the air with distance are 100 cm, 200 cm, 300 cm and 400 cm after solar collector.
- dt1, dt2, dt3, and dt4 are drying tunnel first, second, third, and fourth.
- MCdt1, MCdt2, MCdt3, and MCdt4 are the moisture content of the cocoa beans in the drying tunnel first, second, third, and fourth.

Fig. 3: Photograph of cocoa beans in drying tunnel

4 Results and discussion

The variation of solar radiation and ambient temperature with drying time are shown in Fig.4. The solar radiation is varied between 272 Wm^{-2} and 850 Wm^{-2} was observed, whereas, the average ambient temperature is 29.5°C. As seen from the figure that the ambient air temperature is very dependent on the solar radiation, when solar radiation is high, the ambient temperature is also high, and vice versa.

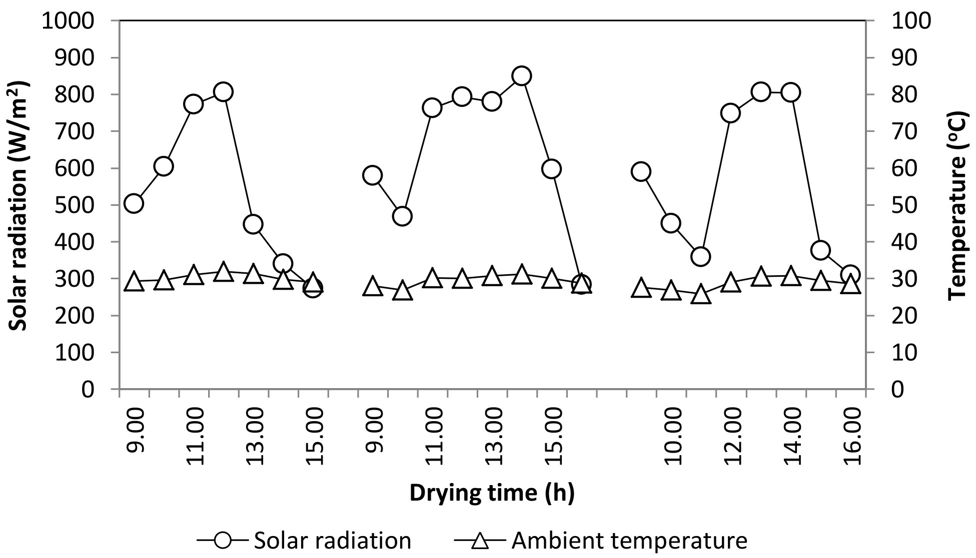

Fig. 4. The variation of solar radiation and ambient temperature with drying time

The variations of air temperature at different positions inside the dryer are shown in Fig. 5. The inlet and outlet air temperature of the heat pump are varied between 26.1°C and 31.9°C, 45.7°C and 50.9°C and in average are about 29.6°C and 48.8°C, respectively. Whereas the outlet air temperature of the solar collector is varied between 40.1°C and 63.2°C, and in average is about 53.0°C, respectively. Whereas the air temperature after solar collector with each distance are 100 cm (T1), 200 cm (T2), 300 cm (T3) and 400 cm (T4) are varied between 42.9°C and 53.7°C, 38.8°C and 55.8°C, 40.8°C and 56.2°C, 39.9°C and 54.4°C and in average are about 48.64°C, 46.33°C, 47.72°C, and 47.68°C, respectively. The air temperature leaving the drying tunnel (T4) is high, and it is potential for recirculating to dry the cocoa beans.

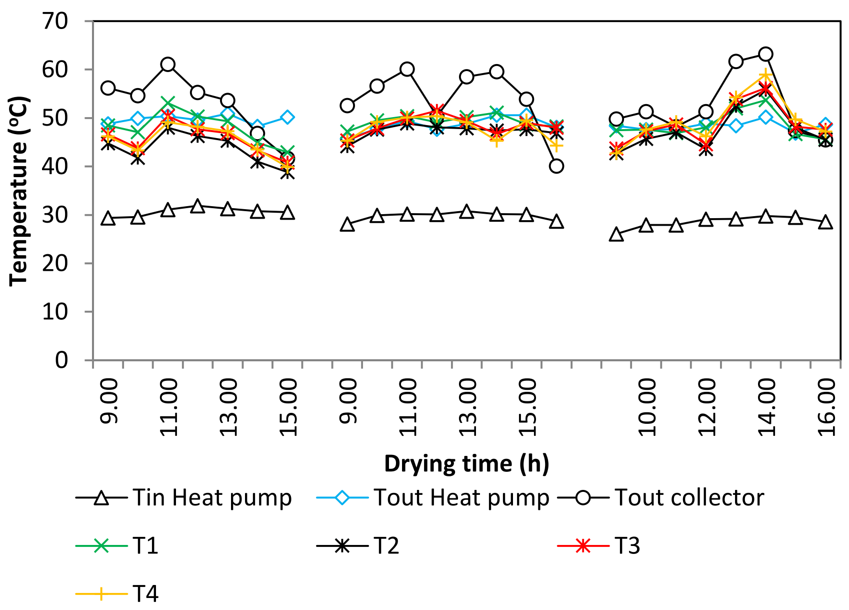

Fig. 5. The variations of air temperature at different positions inside the dryer with drying time

The variation of ambient relative humidity, outlet relative humidity of heat pump, solar collector, and drying tunnel are shown in Fig. 6. The ambient relative humidity is varied between 61.37% and 83.71%, and in average is about 69.79%, respectively. Whereas the outlet relative humidity of heat pump, solar collector, and drying tunnel are varied between 30.84% and 33.82%, 17.1% and 32.02%, 26.2% and 55.33, and in average are about 31.99%, 24.69 % and 36.90%, respectively. As seen from the figure that the air relative humidity of the outlet of the drying tunnel is low and it is potential for recirculating to dry the cocoa beans.

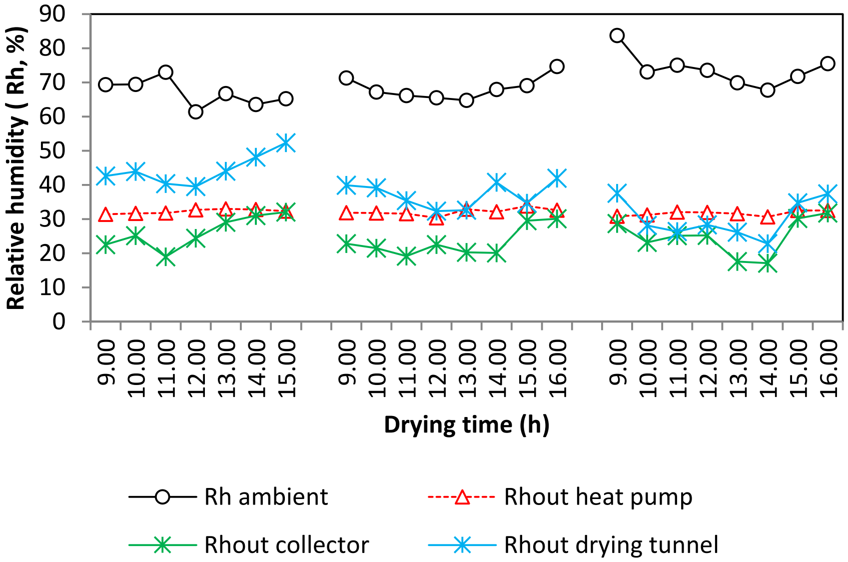

Fig. 6. The variation of ambient relative humidity, outlet relative humidity of heat pump, solar collector, and drying tunnel with drying time

The variation of moisture content of cocoa beans at different positions inside the drying tunnel compared to the cocoa beans dried by open sun drying are shown in Fig. 7. The moisture content of cocoa beans in the dryer was reduced from moisture content of 67% wet basis to moisture content of 8.6% wet basis needed 20 hours whereas the moisture content of cocoa beans was reduced to 26 % wet basis using open sun drying in the same period. As seen from the figure that the reduction of the moisture content of cocoa beans at the first position (MC dt1) inside the drying tunnel faster than other positions, it is because in this position the cocoa beans receive more heat energy. Meanwhile, there is a significant difference between cocoa dried with tunnel dryer and cocoa dried with open sun drying.

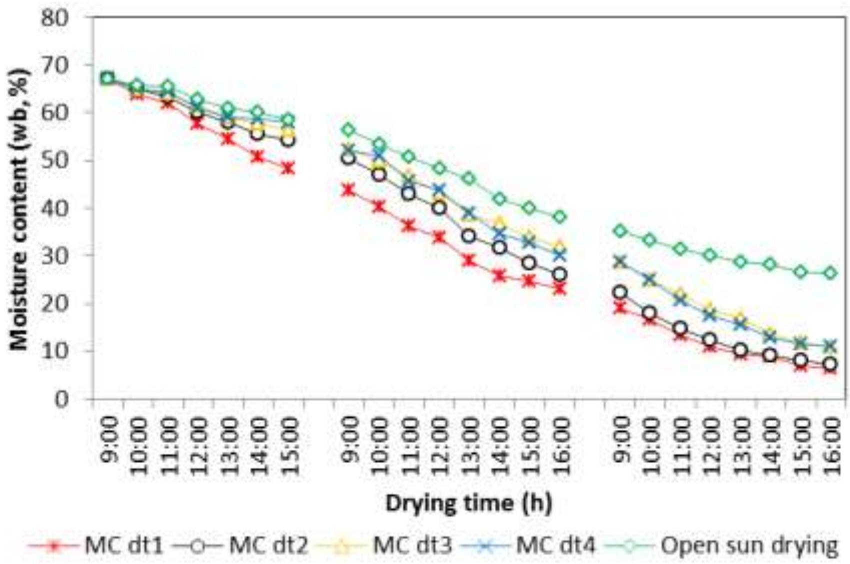

Fig.7. The variation of moisture content of cocoa beans at different positions inside the drying tunnel compared to the cocoa beans dried by open sun drying with drying time

The variation of drying rate with drying time is shown in Fig.8. The drying rate is the mass of water evaporated from the wet cocoa beans per unit time. The minimum, maximum and average the drying rate was estimated of about 0.12 kg/h, 2.91 kg/h, and 1.31 kg/h, respectively. As observed from the figure that the drying rate decreased with increase in drying time. Due to this, the evaporation rate of moisture decreased in the drying time.

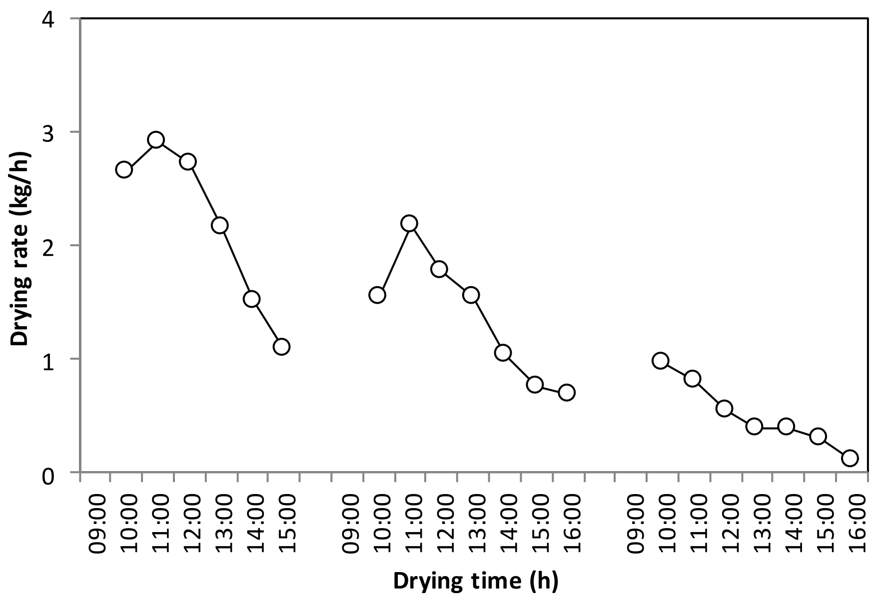

Fig.8. The variation of drying rate with drying time

The variation of drying rate with moisture content wet basis is shown in Fig.9. As seen from the figure that the drying of cocoa beans have two drying periods namely, the constant drying rate period and the falling rate period, and similar results with the observation of earlier researchers [20,21].

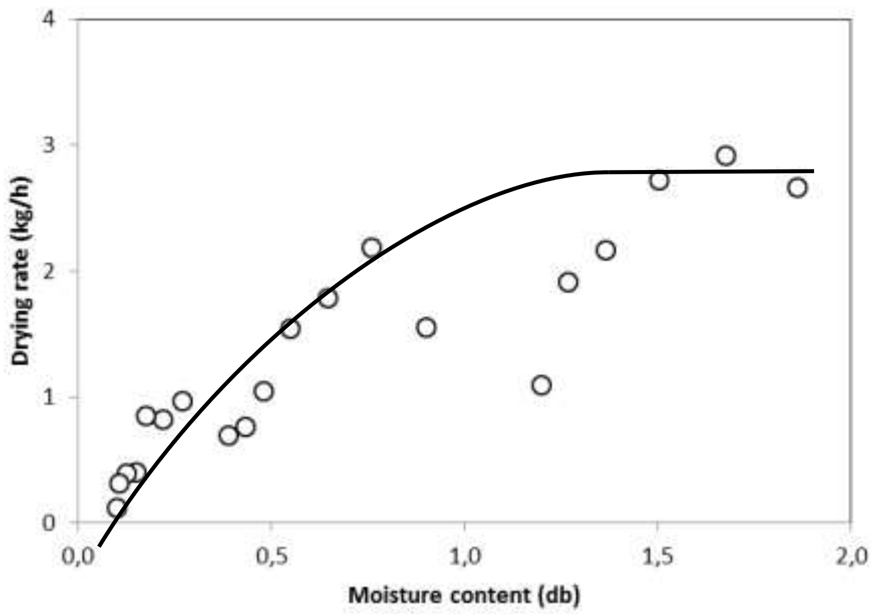

Fig.9. The variation of drying rate with moisture content dry basis

The variations of solar radiation and thermal efficiency of dryer with drying time are shown in Fig.10. The thermal efficiency of dryer is the ratio of the energy used for moisture evaporation to the energy input to drying system [22]. The minimum, maximum, and average of the thermal efficiency of dryer were estimated of about 4.39%, 37.79%, and 19.87%, respectively. As observed from the figure the thermal efficiency of dryer is very sensitive to solar radiation, if the solar radiation fluctuates, the thermal efficiency of dryer also fluctuates.

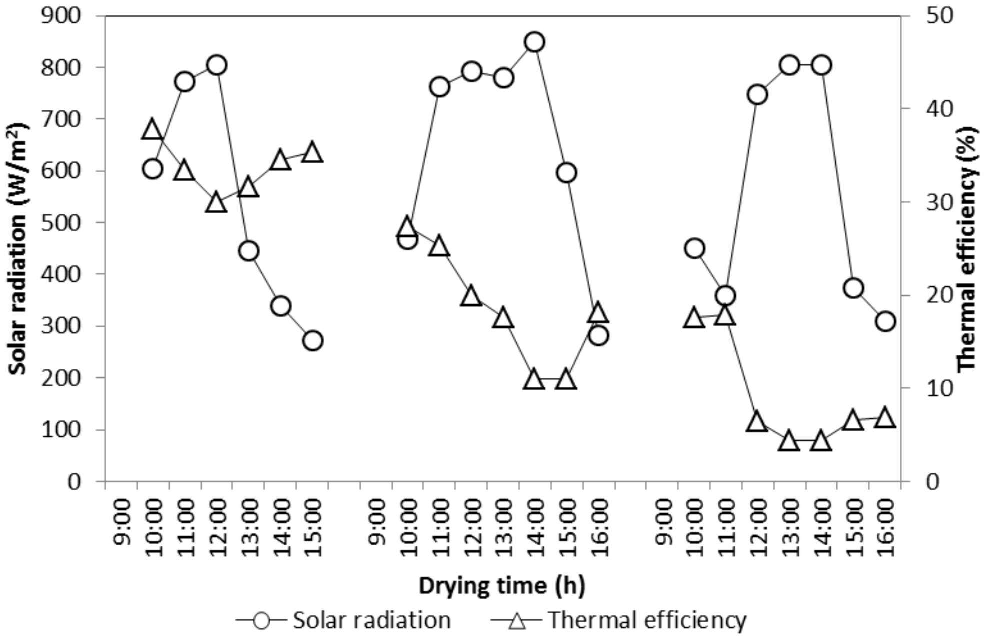

Fig. 10. The variation of solar radiation and thermal efficiency of dryer with drying time

The quality of cocoa beans in term of colour dried by the dryer and open sun drying are shown in Fig. 11. As seen from the figure that the quality of cocoa beans using dryer were better than using open sun drying. This due to the short drying time, the products have no contamination with dust, dirt and other pollutants.

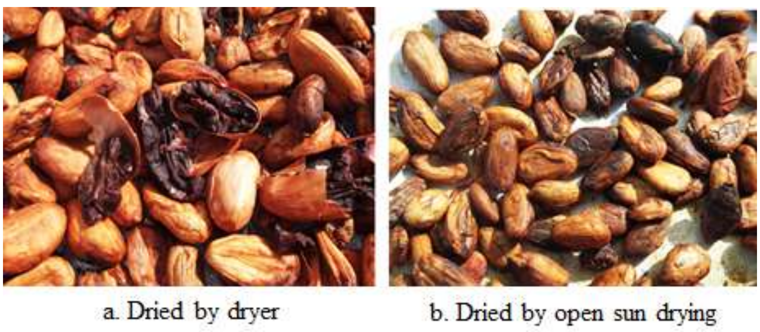

Fig.11. The quality of cocoa beans in term of colour dried by dryer and open sun drying

Conclusions

The drying experiments were carried out at Padang Institute of Technology, West Sumatra, Indonesia. As much as 48 kg with the moisture content of cocoa beans of 67% wet basis in the dryer was reduced the moisture content to 8.6% wet basis needed 20 hours whereas the moisture content of cocoa beans was reduced to 26 % wet basis using open sun drying in the same period. The minimum, maximum and average the drying rate was estimated of about 0.12 kg/h, 2.91 kg/h, and 1.31 kg/h, respectively. The minimum, maximum, and average of the thermal efficiency of dryer were estimated of about 4.39%, 37.79%, and 19.87%, respectively. The drying of cocoa beans have two the drying periods namely, the constant drying rate period and the falling rate period. Result shows that this dryer is capable of drying cocoa beans quickly because of the high drying rate. Also, The quality of cocoa beans in term of colour using dryer were better than using open sun drying, because the short drying time, the products have no contamination with dust, dirt and other pollutants.

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