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# Experimental investigation of the performance of a solar dryer integrated with solid desiccant coloums using water based solar collector for medicinal herb

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**ABSTRACT**

This study is concerned with the analyses of performance on a solar dryer integrated with solid desiccant coloums using water based solar collector. The dryer consists of a solar water collector, two solid desiccant coloums, a water storage tank, two heat exchangers, an air heater, and a drying chamber. The dryer decreased the *Centella asiatica L* moisture content from 88.3% (wb) to 15.9% (wb) within 12 hours, with an average temperature and relative humidity of 45.4°C and 25.8%, respectively. The rate of moisture evaporation and the specific moisture evaporation rate were in the range of 0.001-1.762kg/h and 0.02-0.482 kg/kWh, with 0.594kg/h and 0.169kg/kWh in average values, respectively. The dryer efficiency was in the range of 0.62%-30.4%, with 15.4% in average value. The energy required for moisture evaporation and total energy input to the dryer were in the range of 26.9-1132.2W and 3638.0-4329.7W, with 601.8 W and 3967.4 W in average values, respectively. The efficiency of collector and the heat exchanger effectiveness were in the range of 38.1-50.5% and 65.1-79.7%, with 45.0% and 73.0% in average values, respectively. The result shows that the dryer is suitable for drying *Centella asiatica* L, this is due to the low temperature of drying air and high moisture evaporation rate.

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## NOMENCLATURE

| | |
|---|---|
| $A_C$ | Solar water collector area ($m^2$) |
| $C_{Pw}$ | Specific heat of water ($Jkg^{-1}C^{-1}$) |
| $H_{fg}$ | Latent heat of water vaporization (kJ/kg) |
| $I_T$ | solar radiation ($Wm^{-2}$) |
| $M_{db,t}$ | Moisture content at the time "$t$" (db) |
| $M_{db,t+\Delta t}$ | Moisture content at the time "$t + \Delta t$" (db) |
| $m_{dca}$ | Mass of bone dry of *Centella asiatica L* (kg) |
| MER | Rate of moisture evaporation (kg/h) |
| $m_{wetca}$ | Mass of wet of *Centella asiatica L* (kg) |
| $\dot{m}_w$ | Water mass flow rate (kg/s) |
| $Q_{air\ heater}$ | Electrical energy for air heater (W) |
| $Q_B$ | Electrical power for blower (W) |
| $Q_P$ | Electrical power for water pump (W) |

| | |
|---|---|
| $Q_S$ | Energy incident on the surface of the solar water collector (W) |
| $RH_{i,DC}$ and $RH_{o,DC}$ | Relative humidity entering and leaving drying chamber (%) |
| $T_{ai,DC}$ and $T_{ao,DC}$ | Air temperature air entering and leaving drying chamber (°C) |
| $T_{ai,HE1}$ and $T_{ai,HE2}$ | Air temperature at inlet heat exchanger 1and 2 (°C) |
| $T_{ao,HE1}$ and $T_{ao,HE2}$ | Air temperature at outlet heat exchanger 1 and 2 (°C) |
| $T_{ai,HT}$ and $T_{ao,HT}$ | Air temperature entering and leaving auxiliary air heater (°C) |
| $T_{ai,SDC1}$ and $T_{ai,SDC2}$ | Air temperature entering solid desiccant coloum 1 and 2 (°C) |
| $T_{ao,SDC1}$ and $T_{ao,SDC2}$ | Air temperature leaving solid desiccant coloum 1 and 2 (°C) |
| $T_{w,S}$ | Water temperature in storage tank (°C) |
| $T_{wi,C}$ and $T_{wo,C}$ | Water temperature entering and leaving collector (°C) |
| $T_{wi,HE1}$ and $T_{wi,HE2}$ | Water temperature at inlet heat exchanger 1 and 2 (°C) |
| $T_{wo,HE1}$ and $T_{wo,HE2}$ | Water temperature at outlet heat exchanger 1 and 2 (°C) |
| db | Dry basis |
| wb | Wet basis |
| $\Delta t$ | Drying time interval (h) |

## 1. INTRODUCTION

*Centella asiatica L* (umbelliferae) has been used as a medicinal herb since time immemorial in Indonesia, Malaysia, China, India and other parts of Asia [1]. The herb is rich in nutrients and pentacyclic triterpenes [2]. It can be used for improving memory [3], antibacterial and antifungal [4], antigenotoxic [5], antitumor [6], anti-stress [7], and antiproliferative [8].

*Centella asiatica L* after harvested is highly perishable because it contains high moisture (80-90% wet basis) and having a short storage life. To increase storage life the *Centella asistica* L must be dried. In developing countries solar dryer of hot air type is the dominant method that is used for drying medicinal herbs. Recently, various of types of medicinal herbs have been dried using the solar dryers of hor air type such as: black ginger [9], lemon verbeva leaves [10], curcuma [11], mint [12], [13], rosella [14], [15], *Valeriana jatamansi* [16], red pepper [17], wild ginger [18], *Centella asiatica* [19], thymus and mint [20], jerky [21], *Andrographis paniculata* [22], green tea [23], fenugreek leaves [24], and onion slice [25].

However, the moisture evaporation rate of the solar dryer of hot air type depends on the temperature of the drying air, to increase the moisture evaporation rate, it is conducted by increasing the temperature of the drying air. The high drying air temperature is not suitable for drying medicinal herb because it is heat sensitive products and results in low quality drying.

To overcome this problem, low temperature solar drying technologies must be used with high moisture evaporation rate to maintence the quality of drying products. This can be done by two methods, namely by integrating a heat pump system or a solid desiccant system into a solar dryer. In both of these methods, the moisture evaporation rate can be increased by dehumidifying of the moisture in the drying air by using an evaporator of heat pump and desiccant materials, respectively.

Several researchers have integrated and tested solar dryers with heat pump using air and water based solar collectors for drying various of types the medicinal hebrs and heat sensitive products, for using air based solar collectors such as: curcuma [26], tomato [27], banana [28], mint leaves [29], tomato, strawberry, mint, and parsley [30], agricultural food grains [31], and corn [32]. For using water based solar collectors such as: wheat [33], banana chip [34], radish [35], and mushroom [36]. However, dehumidification of the moisture in drying air can be achieved if the surface temperature of the evaporator is lower than the temperature of dew point of the drying air at inlet of the evaporator [37].

Meanwhile, several researchers have also integrated and tested solar dryers with solid desiccant bed using air based solar collector for drying various of types the medicinal hebrs and heat sensitive products such as: chili [38], green peas and pineapple slices [39], green peas [40], apricots [41], and maize [42]. And also, solar dryers integrated with desiccant wheel using water based solar collector have been tested for drying oil palm fronds and kenaf core fiber, respectively [43], [44]. The researchers found that the dryers are capable to dry the medicinal herbs and heat sensitive products because of the high moisture evaporation rate (short drying time), and high quality of the dryng product due to hot and dry air (low drying air temperature).

However, no work on experimental performance of solar dryer integrated with solid desiccant coloum using water based solar collector for drying *Centella asiatica L*, (medicinal herb) has been reported. Therefore, the present study aims to evaluate the performance of a solar dryer integrated with solid desiccant coloum using water based solar collector for drying *Centella asiatica L*.

## 2. RESEARCH METHOD

### 2.1. Experimental set-up

The photograph and schematic of the solar dryer integrated with solid desiccant coloums using water based solar collector as shown in Figure 1 and Figure 2. The dryer consist of a solar water collector

(Figure 3), two water-air heat exchanger (Figure 4), two solid desiccant coloums (Figure 5), a drying chamber (Figure 6), a water storage tank (Figure 7), and an auxiliary air heater (Figure 8). The drying system has three processes, namely dehumidification, drying, and regeneration processes. The dehumidification is the process to remove the moisture from drying air using a solid desiccant, the drying is the process to remove the moisture from the *Centella asiatica L*, while the regeneration is the process to remove the moisture from the solid desiccant using hot air. The main components of the dryer specification and characteristic are presented in Table 1.

Figure 1. Photograph of the solar dryer integrated with solid desiccant coloums using water based solar collector

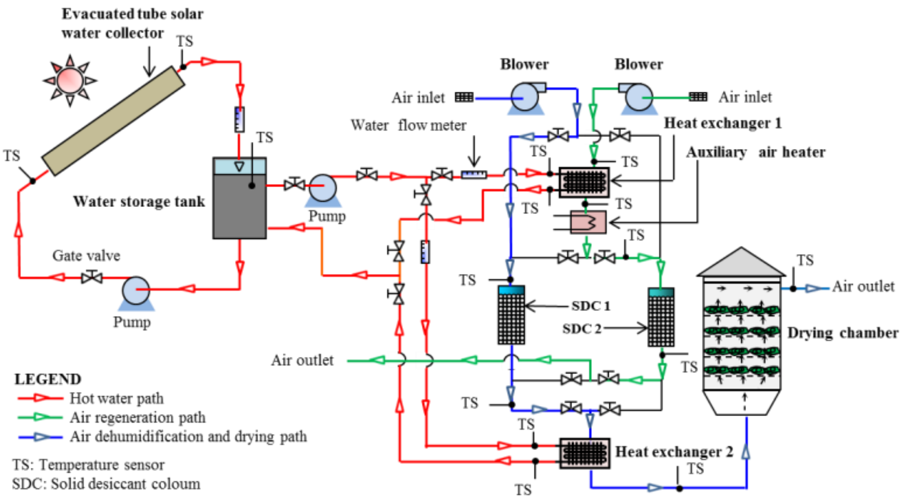


Figure 2. Schematic of the solar dryer integrated with solid desiccant coloums using water base solar collector

Figure 3. Photograph of the evacuated tube solar water collector

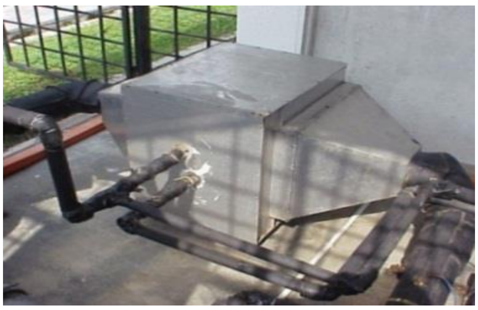

Figure 4. Photograph of the heat exchanger

Figure 5. Photograph of the solid desiccant coloums

Figure 6. Photograph of the drying chamber

Figure 7. Photograph of the water storage tank

Figure 8. Photograph of the auxiliary air heater

Tabel 1. Main components specifications and characteristics of the drying system

| Component | | Specification and characteristic |
|---|---|---|
| 1 | Solar water collector | |
| | a. Type | Evacuated tube |
| | b. Tube number | 60 |
| | c. Area | 6 $m^2$ |
| | d. Manufacturer | Apricus Solar, China |
| 2 | Water storage tank | |
| | a. Capacity | 80 L |
| | b. Insulation | Glass wool and rubber foam |
| 3 | Solid desiccant columns | |
| | a. Dimensions | 0. 25 m x 0.25 m x 1m |
| | b. Desiccant material | Silica gel (Chemxin, China) |
| | c. Coloum number | 2 |
| 4 | Drying chamber | |
| | a. Type | Cabinet |
| | b. Dimensions | 1m x 1m x 2.5m |
| | c. Tray number | 3 |
| | d. Tray material | Stainless steel wire mesh |
| 5 | Heat exchanger | |
| | a. Type | Cross flow plate (water-air heat exchanger) |
| | b. Number | 2 |
| 6 | Auxiliary air heater | |
| | a. Type | U Type stainless steel finned electric tubular |
| | b. Capacity | 0.75 kW |
| | c. Manufacturer | Superb Heater Technology, Shenzen, China |
| 7 | Blower | |
| | a. Type | Centrifugal |
| | b. Number | 2 |
| | c. Capacity | 0.75 kW |
| | d. Manufacturer | Xinxiang Blower Factory, China |
| 8 | Water pump | |
| | a. Type | Centrifugal |
| | b. Number | 2 |
| | c. Capacity | 0.1 kW |
| | d. Manufacturer | Asiatic Engineering, Japan |

### 2.2. Experimental procedure

The drying experiment was carry out in two days, the experiment was carry out from 10:00 AM to 4:00 PM. For drying experiments, the fresh *Centella asiatica L* is purchased from the local market. About 3 kg of the *Centella asiatica L* was filled into each tray in the chamber of dryer for the experiment. The drying chamber has three trays, and the photograph of the *Centella asiatica L* as shown in Figure 9. The *Centella asiatica L* was weighed every 1 h, and temperature and solar radiation was recorded every 1 h. Characteristic of various measurement which used in drying experiment are presented in Table 2.

Figure 9. Photograph of the *Centella asiatica L*

Tabel 2. Characteristics of measurement of the drying system

| Measuring Device | Type of measurement | Range | Accuracy |
|---|---|---|---|
| K type thermocouple | Temperature | -270°C to 1260°C | 2.2°C |
| LI-200 pyranometer | Solar radiation | 0-2000 $Wm^{-2}$ | ± 0.1$Wm^{-2}$ |
| AH4000 data logger | Data transfer device | 12 channel | ± 0.1°C |
| HT-383 anemometer | Air velocity | 0-30 $ms^{-1}$ | ± 0.1 ms-1 |
| 1250A water rotameter | Water flow rate | 0.1-10 Lpm | ± 5% |
| TKB-0.15 weighing | weight change | 0-15 kg | ± 0.05kg |

### 2.2. Experimental data analysis

The efficiency of collector, the effectiveness of heat exchanger, the moisture content (wb), the moisture evaporation rate (MER), the specific moisture evaporation rate (SMER), the energy required for evaporation of moisture ($Q_{ev}$), the total energy input to dryer ($Q_{in}$), and the dryer efficiency were determined by using equaitions in Table 3 [21], [26], [28], [29], [35], [36], [45]. The obtained data for performance analysis during drying of *Centella asiatica L* in two day drying experiments are presented in Table 4 on Appendix.

Tabel 3. Performance analysis

| Performance indications | Performance equation | Eq.no. |
|---|---|---|
| Solar water collector efficiency | $\eta_{coll} = \frac{\dot{m}_w C_{Pw}(T_{wo,C} - T_{wi,C})}{I_T A_C} \times 100\%$ | (1) |
| Heat exchanger effectiveness | $\varepsilon = \frac{T_{ao,HE} - T_{ai,HE}}{T_{wi,HE} - T_{ai,HE}}$ | (2) |
| Moisture content (wb) | $M_{wb} = \frac{m_{wetca} - m_{dca}}{m_{wetca}}$ | (3) |
| Rate of moisture evaporation | $MER = \frac{M_{db,t+\Delta t} - M_{db,t}}{\Delta t}$ | (4) |
| Specific moisture evaporation rate | $SMER = \frac{MER}{Q_{in}}$ | (5) |
| Energy required for evaporation of moisture | $Q_{ev} = MER H_{fg}$ | (6) |
| Total energy input to the dryer | $Q_{in} = Q_S + Q_B + Q_P + Q_{airheater}$ | (7) |
| Dryer efficiency | $\eta_{th} = \frac{Q_{ev}}{Q_{in}}$ | (8) |

## 3. RESULTS AND ANALYSIS

The solar radiation, efficiency of collector, and effectiveness of heat exchanger variations with drying time are presented in Figure 10. As seen from the figure the weather is quite sunny, the solar radiation ranged between 409.0 and 930.4Wm$^{-2}$, with 703.6Wm$^{-2}$ in average value was recorded. The efficiency of collector ranged between 38.1 and 50.5%, with average value of 45.0%, at a water velocity of 0.39m/s. The effectiveness of heat exchanger was in the range of 65.1-79.7%, with average value of 73.1%, at a water and an air velocity of 0.29m/s and 3.25m/s, respectively. As observed from the Figure 10 the efficiency of collector is quite high, this due to the heat convective loss is low because of the high thermal resistance between absorber flat and cover glass or the internal pressure below 0.5 Pa (Vacuum).

The air temperature and relative humidity variations entering and leaving drying chamber versus drying time are presented in Figure 11. The air temperature entering and leaving the drying chamber were in the range of 36.8$^{o}$C-49.8$^{o}$C and 31.5$^{o}$C-49.1$^{o}$C, with average values of 45.4$^{o}$C and 38.9$^{o}$C, respectively. Whereas, the relative humidity entering and leaving the drying chamber ranged between 20.0% and 35.1%, and 27.8% and 66.7%, with 25.8% and 48.0% in average values, respectively. As seen from figure that the air temperature increased and relative humidity decreased leaving drying chamber with increasing in drying time. This due to, the heat and mass transfers decreased in the drying time.

The *Centella asiatica L* moisture content and moisture evaporation rate variations versus drying time are presented in Figure 12. The *Centella asiatica L* moisture content was reduced to 15.9% (wb) from 88.3% (wb) within 12 hours, with average air temperature of 45.4$^{o}$C and average relative humidity of 25.8% at an air velocity of 3.25m/s. Whereas, the moisture evaporation rate (MER) was in the range of 0.001-1.762kg/h, with 0.594kg/h in average value. Referring to Figure 12, the moisture evaporation rate decreased with increase by time, this due to the mass transfer rate decreased by time.

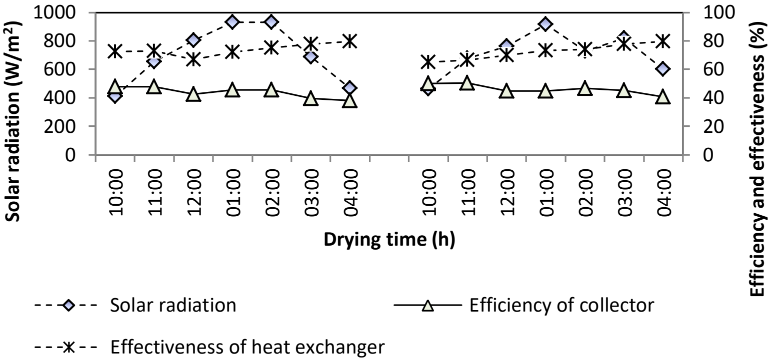


Figure 10. Solar radiation, collector efficiency and effectiveness of heat exchanger with drying time

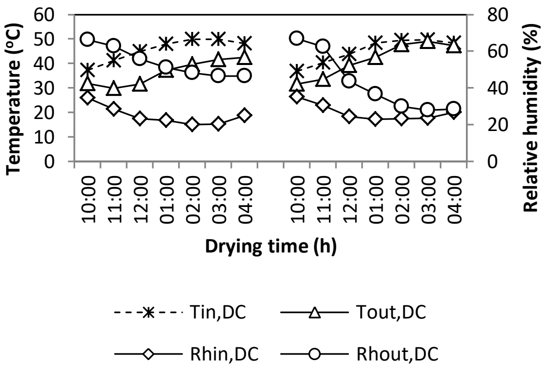


Figure 11. Temperature and relative humidity vs drying time

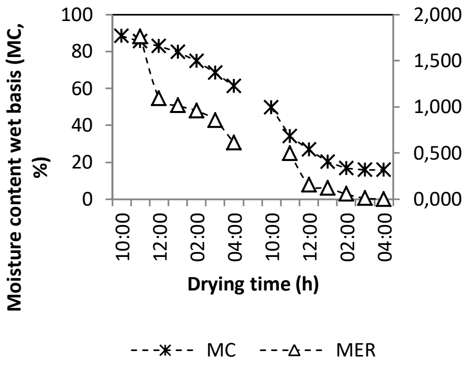


Figure 12. Moisture content and MER vs drying time

The SMER variations versus drying time is presented in Figure 13. The SMER ranged between 0.02 and 0.482kg/kWh, with 0.169kg/kWh in average value. As observed from the figure that the SMER decreased with increase by time. This due to, the rate of moisture evaporation decreased in time. The dryer efficiency, energy required for moisture evaporation, and total energy input to the dryer variations versus drying time are shown in Figure 14. The dryer efficiency ranged between 0.62% and 30.4%, with average value of 15.4%. Whereas, the energy required for evaporation of moisture and the total energy input to the dryer were in the range of 26.9W-1132.2W and 3638.0W-4329.7W, with average values of 601.8W and 3967.4, respectively.

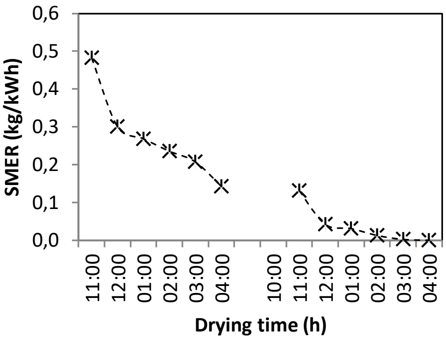


Figure 13. SMER vs drying time

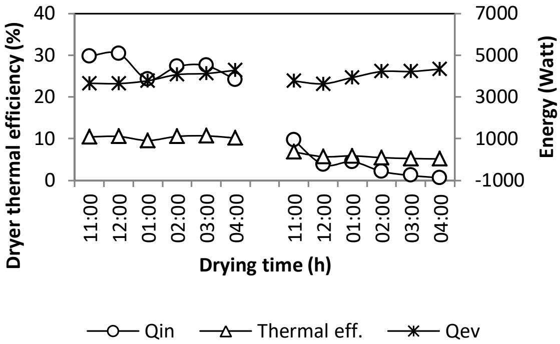


Figure 14. Dryer efficiency and energy vs drying time

## 4. CONCLUSIONS

In this study, a solar dryer integrated with solid desiccant coloums using water based solar collector was tested for drying *Centella asiatica* L. The results of experiment indicated that he dryer decreased the *Centella asiatica L* moisture content from 88.3% (wb) to 15.9% (wb) in 12 hours, with average air temperature of 45.4°C and average relative humidity of 25.8%, at 3.25 m/s air velocity. The average of MER was 0.594kg/h. The average of SMER was 0.169 kg/kWh. The average of dryer efficiency was 15.4%. The average of energy required for evaporation of moisture was 601.8 W. The average of total energy input to the dryer was 3967.4 W. The average of water collector efficiency was 45.0%. The average of heat exchanger effectiveness was 73.1%

The result shows that the dryer is suitable for drying *Centella asiatica* L, this is due to the low temperature of drying air and high moisture evaporation rate.

## APPENDIX

Table 4. Operating input and output parameters during dying *Centella asiatica L.*

| Time | Mass ($M_{CA}$) | Solar radiation (W/m²) | Temperature (°C) | | | | | | | | | | | | | | | Relative humidity (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (h) | (kg) | $I_T$ | $T_{wi,C}$ | $T_{wo,C}$ | $T_{w,S}$ | $T_{wi,HE1}$ | $T_{wo,HE1}$ | $T_{ai,HE1}$ | $T_{ao,HE1} = T_{ai,HT}$ | $T_{ao,HT} = T_{ai,SDC2}$ | $T_{ao,SDC2}$ | $T_{ai,SDC1}$ | $T_{ao,SDC1} = T_{ai,HE2}$ | $T_{wi,HE2}$ | $T_{wo,HE2}$ | $T_{ao,HE2} = T_{ai,DC}$ | $T_{ao,DC}$ | $RH_{i,DC}$ | $RH_{o,DC}$ |
| First day drying experiment | | | | | | | | | | | | | | | | | | | |
| 10:00 | 9.00 | 409.00 | 38.10 | 39.53 | 39.10 | 38.65 | 38.23 | 30.50 | 36.40 | 56.70 | 32.60 | 29.60 | 36.50 | 38.65 | 38.37 | 37.28 | 31.75 | 34.50 | 66.20 |
| 11:00 | 7.24 | 655.60 | 42.30 | 44.60 | 44.05 | 43.62 | 42.99 | 32.50 | 40.60 | 59.80 | 38.09 | 31.40 | 40.80 | 43.78 | 42.95 | 41.16 | 29.90 | 28.40 | 62.70 |
| 12:00 | 6.15 | 802.25 | 48.00 | 50.49 | 49.68 | 49.27 | 48.46 | 34.50 | 44.40 | 59.90 | 40.02 | 33.50 | 42.00 | 49.15 | 48.70 | 44.80 | 31.52 | 23.30 | 55.70 |
| 1:00 | 5.13 | 929.27 | 53.00 | 56.10 | 55.13 | 54.63 | 53.56 | 35.20 | 49.20 | 59.90 | 41.10 | 34.20 | 41.70 | 55.01 | 53.66 | 48.00 | 37.35 | 22.40 | 51.20 |
| 2:00 | 4.17 | 930.43 | 55.10 | 58.21 | 57.31 | 56.94 | 55.85 | 36.60 | 51.90 | 59.90 | 41.98 | 37.00 | 41.80 | 56.85 | 55.91 | 49.80 | 39.70 | 20.02 | 48.20 |
| 3:00 | 3.32 | 686.00 | 55.10 | 57.08 | 56.31 | 56.00 | 55.05 | 34.90 | 51.30 | 59.90 | 43.07 | 34.00 | 39.20 | 55.97 | 55.55 | 49.80 | 41.68 | 20.20 | 46.50 |
| 4:00 | 2.71 | 466.22 | 52.80 | 54.10 | 53.71 | 53.31 | 52.66 | 35.00 | 49.60 | 59.90 | 45.01 | 34.20 | 38.80 | 53.36 | 53.17 | 48.20 | 42.51 | 25.10 | 46.50 |
| Second day drying experiment | | | | | | | | | | | | | | | | | | | |
| 10:00 | 2.09 | 464.67 | 37.20 | 38.90 | 38.27 | 37.86 | 37.52 | 31.10 | 35.50 | 59.20 | 30.00 | 30.10 | 36.60 | 38.18 | 38.13 | 36.80 | 31.51 | 35.10 | 66.70 |
| 11:00 | 1.59 | 675.98 | 41.50 | 44.00 | 43.10 | 42.82 | 42.32 | 33.50 | 39.70 | 59.80 | 39.60 | 32.70 | 39.95 | 43.03 | 42.83 | 40.40 | 33.51 | 30.60 | 62.30 |
| 12:00 | 1.44 | 762.87 | 47.70 | 50.20 | 49.22 | 48.87 | 48.16 | 34.30 | 44.50 | 59.80 | 40.70 | 33.40 | 40.30 | 48.89 | 48.34 | 43.80 | 39.21 | 24.50 | 43.50 |
| 1:00 | 1.32 | 917.32 | 53.50 | 56.50 | 55.53 | 54.92 | 54.04 | 36.60 | 50.00 | 59.90 | 40.90 | 34.50 | 40.30 | 55.10 | 53.46 | 48.30 | 42.40 | 23.00 | 36.60 |
| 2:00 | 1.26 | 728.96 | 55.50 | 58.00 | 57.00 | 56.43 | 55.43 | 35.90 | 51.10 | 59.90 | 40.55 | 35.10 | 39.50 | 56.17 | 55.74 | 49.40 | 47.64 | 23.20 | 30.02 |
| 3:00 | 1.25 | 820.33 | 55.50 | 58.21 | 57.30 | 56.85 | 55.85 | 36.40 | 52.30 | 59.90 | 43.10 | 35.20 | 39.40 | 56.78 | 55.00 | 49.60 | 49.05 | 23.50 | 27.88 |
| 4:00 | 1.25 | 602.08 | 53.70 | 55.50 | 54.88 | 54.58 | 53.61 | 34.50 | 50.50 | 59.80 | 44.75 | 33.70 | 38.60 | 54.23 | 52.62 | 48.30 | 47.25 | 26.70 | 28.50 |

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