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Performance Study of Hybrid Solar Dryer for Cassava Starch

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Abstract. An experiment has been performed to study the performance of hybrid solar dryer for cassava starch. This paper introduces a drying method in which solar dryer is combined with Liquefied Petroleum Gas as an auxiliary heater to support the drying process. Drying experiment was carried out from 10.00 to 13.00 with the dryer temperature of 40, 50, and 60 °C. The profiles of temperature, relative humidity, and solar intensity were very dependent of weather condition, geographical condition and location, and measurement time. Only the final moisture content from drying at 60 °C that could satisfy the maximum limit of cassava starch's moisture content. It is found that higher temperature will lead to faster and more effective drying. The fastest moisture reduction occurred at the first tray, followed by the second and the third tray. The value of drying rate was high when the moisture content is still high, then gradually decreased as moisture content decreased. In this drying process, the constant rate period occurred very quickly, namely during the initial phase of the drying process. The drying process of cassava starch mostly happens in the falling rate period. The highest value of effectivity factor was recorded at 11.00, with the highest value of 6.4

INTRODUCTION

In 2017, Indonesia ranks fourth in cassava production, behind Nigeria, Democratic Republic of Congo, and Thailand, with 19.046 million tons.[1] During the recent years, the needs of cassava starch in Indonesia have increased rapidly, especially from industries that utilized cassava starch as its main material. In addition to its application for food, cassava starch is also utilized by several industries such as paper, batik, or plywood industries. There are several steps needed to produce cassava starch, one of them is drying, which is the most important step. Drying is a complex process that involves heat and mass transfer between the product and the surrounding medium.[2] The purpose of drying is to reduce the product's water content until it reaches safe limit, at which the growth of microorganisms or enzymes that might cause deterioration begin to halt. Therefore the dried product will have longer shelf life.[3] The drying technology of cassava starch industry may be divided in three, namely traditional (conventional open sun drying), semi-modern (drying process is performed by oven), and fully-automated cassava starch industry.[4]

The maximum allowable moisture content allowed on cassava starch according to the National Standard of Indonesia (SNI) is 15%,[5] which means the drying step is indeed important. At the small-scale industries, due to the weather limitations, the production of cassava starch becomes seasonal job. Although does not require any additional energy, open sun drying is not efficient, due to the long drying time, low drying rate, prone to outside interventions (insects, wind, dust, etc.) and heavily reliant to weather. This will cause the non-uniformity of the cassava starch's moisture content.[6] Hence, it is required to develop a new technology that can solve the problems stated above. One of them is by using solar dryer. Solar drying is a drying method that utilizes sun's radiation as the heat source. This method is cheap and can be implemented easily, because it only needs sun as its primary energy source.[7] Generally, a solar dryer consists of a closed chamber which contains the dried product. Inside the chamber, there are several tray

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to place the product, and the closed design of this dryer will prevent outside interventions as stated in the previous paragraph.

Several studies about solar dryer have been performed. A study about forced-convection solar dryer integrated with gravel as heat storage material for chili drying reported that the inclusion of heat storage helps maintain the dryer temperature and enables the dryer to be operated at longer time, which is 4 hours. The efficiency of the solar dryer used is 21%.[8] Meanwhile, another study about design and testing of indirect solar dryer for industrial scale states that forced convection solar drying is more effective than natural ventilation. The designed dryer was able to reduce tomato's moisture content from approximately 93% wet basis to 12% wet basis.[9]

Some studies have reported cassava drying and its behaviors using different types of dryer. A study about the agglomeration mechanisms of cassava starch during pneumatic conveying drying states that the agglomeration of cassava starch happened when starch was in the rubbery phase, which is during the early stage of the drying process. In order to reduce starch's agglomeration during the drying process, the starch should be dried at temperature lower than its glass transition temperature.[10] Another research studied the energy and exergy analyses of native cassava starch drying in a tray dryer and it is found that moisture content decreased with increase in time until the dynamic equilibrium moisture content is reached. Drying time and dynamic equilibrium moisture content decreased from 480 to 270 minutes and 7.7 to 1.7% dry basis as the drying temperature increased from 40 to 60 ^{o}C.[11] Another study discussed the effect of temperature and shape on drying performance of cassava chips. Cassava chips were cut into rectangular and circular shapes, with the drying temperature of 60, 80, 100, and 120 ^{o}C. It is found that the rectangular chips dried at 100 ^{o}C give the best results because they have soft, white color, which is desirable for cassava starch manufacture and required less drying time compared to the circular ships.[12]

However, despite of many advantages it proposes, solar dryer still relies on the weather. If the weather is cloudy, the drying process will not be efficient.[6] Based on problems stated above, in this research, a new drying method is used, namely hybrid solar dryer. It utilizes LPG (Liquefied Petroleum Gas) as an auxiliary heater to support the solar dryer (hence the name is "hybrid" solar dryer). The addition of LPG will enable the solar dryer to operate even during bad weather. One important advantage of hybrid solar dryer over normal solar dryer is the flexibility of the drying process, because the temperature can be set as desired, therefore the final moisture content of the product can be controlled. In this research, a new design of hybrid solar dryer was introduced, and in order to assess its performance, the dryer was used for cassava starch drying. Therefore, the purpose of this research is to study the performance of hybrid solar dryer for cassava starch drying. drying curve and drying rate of cassava starch using hybrid solar dryer. The effectivity factor of hybrid solar dryer was also studied in order to measure how efficient the hybrid solar dryer used compared to the open sun drying. The temperature profiles and the effects of solar radiation on the drying process were also investigated.

EXPERIMENTAL PROCEDURE

Figure 1 shows the schematic diagram of hybrid solar dryer used in this experiment with the parts, while figure 2 shows the hybrid solar dryer in use. Basically the hybrid solar dryer system consisted of drying chamber, solar collector unit, and blower and burner unit. The drying chamber contains four drying trays and the trays were made from wire net, each tray was covered with aluminium at the edges of the each trays. The outside frame of the drying chamber were covered by aluminium because aluminium is strong, light, and able to help conductng heat into the drying chamber. At the top of the drying chamber, an exhaust fan was installed in order to blow out the humid drying air from inside the drying chamber. The solar collector frames were also covered by aluminium and a black absorber sheet made from thermoplastic rubber was placed inside the solar collector chamber in order to absorb the solar radiation. At the bottom part of the the collector, nine holes were made so that ambient air could flow convectively through the collector. At the left side of the drying chamber, a pipe was installed which will be used to connect the drying chamber with the blower and burner unit. Figure 3 shows the blower and burner unit. The blower sucked the ambient air and then blow the air to the drying chamber through pipe that connected the burner unit and the drying chamber. Before entering the drying chamber, the air will be heated using heat obtained from burning the LPG, as an auxiliary heat source. A control panel which acted as a temperature indicator and to turn on/turn off the blower-burner system was installed. This enables the drying process to be controlled as desired.

All drying experiments were performed in the Laboratory of Chemical Engineering Department, Diponegoro University, Semarang, Indonesia. The material needed in this experiment is wet cassava starch (obtained from Small-Medium Enterprise of cassava starch from Pati, Middle Java, Indonesia) with initial moisture content of 39.93 % wet basis. The initial moisture content determination was done according to the AOAC method.[13] The tools needed are digital weigher, temperature and Relative Humidity meter (@Krisbow S000052505), solar intensity meter, and plastic sheet. There were 2 drying modes performed in this experiment, namely hybrid solar drying and open sun drying. For open sun drying, 100 grams of wet cassava starch was placed above the plastic sheet, then dry it under the sun for three hours, from 10.00 to 13.00. The sample weight was measured once every 30 minutes. This data is required to analyze the effectivity factor of hybrid solar dryer.

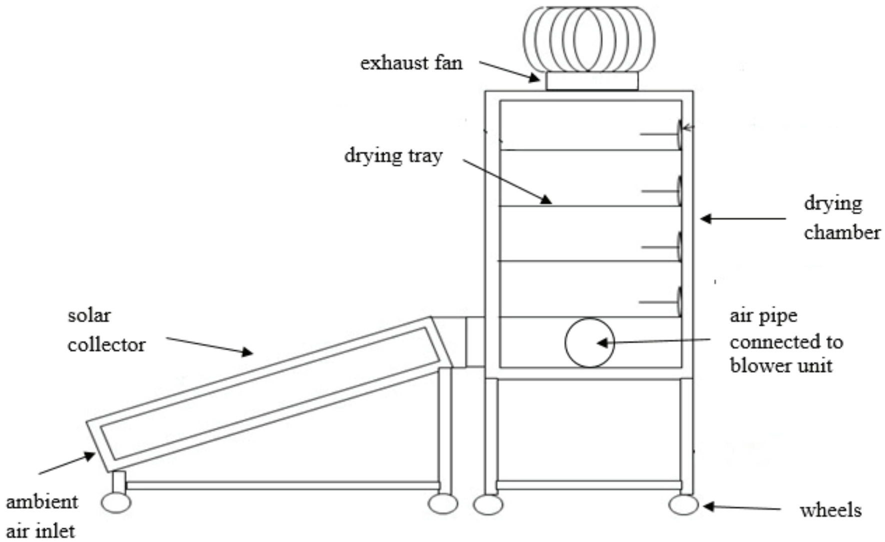

FIGURE 1. Schematic diagram of hybrid solar dryer used in this experiment

FIGURE 2. Hybrid solar dryer

FIGURE 3. Blower and Burner unit

As for hybrid solar dryer, the independent variable is the drying temperatures, which were set at 40, 50, and 60 °C, respectively. To begin the experiment, 3 samples @100 grams of wet cassava starch were prepared. Next, the dryer is prepared by connecting the solar dryer to the burner whose heat is supplied by LPG. Then, turn on the dryer, turn on the blower, and set the dryer temperature as desired, according to the variables. After that, put the samples to the three trays inside the drying chamber. Drying process was performed for three hours, from 10.00 to 13.00. Using its respective measurement tools, the temperature, RH, and solar intensity was measured once every 30 minutes. Temperatures of the dryer air inlet, dryer chamber, and dryer outlet were measured. The above steps were repeated for each different drying temperature.

DATA ANALYSIS

After the drying was finished, the measured data were processed. Then, several analysis were performed based on the said data, such as:

Moisture Content Analysis

Based on the measurements of cassava starch's weight every 30 minutes, the moisture content of cassava starch at particular time can be determined using Equation 1.

$$X = \frac{m_t}{m_t + m_d} \tag{1}$$

Where X is the moisture content, m_t is the mass of cassava starch at any given time, and m_d is the mass of dry cassava starch

Drying Rate Analysis

Aside from being used to determine the moisture content, the cassava starch's weight can also be used to determine the drying rate (R_d, in gram/minutes) at any given time (t), using Equation 2.[14]

$$R_d = \frac{m_t - m_d}{t} \tag{2}$$

Effectivity Factor Analysis

The effectivity factor (*ef*) can be determined by dividing the drying rate obtained from hybrid solar drying (R_{dso}) and the drying rate obtained from open sun drying (R_{dsu}), as shown in Equation 3.[15]

$$ef = \frac{R_{dso}}{R_{dsu}} \tag{3}$$

RESULTS AND DISCUSSION

Analysis of Temperature, Relative Humidity, and Solar Intensity Profiles

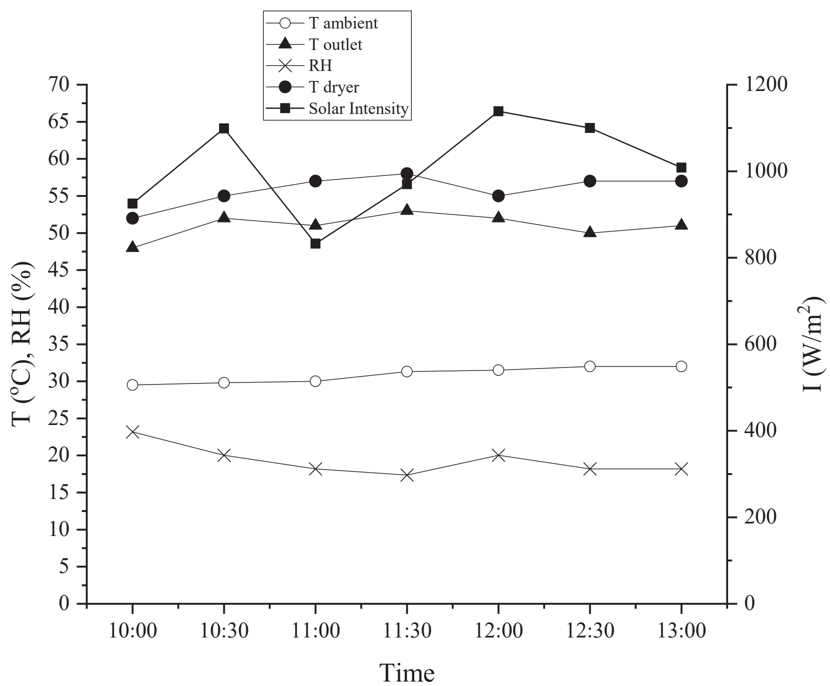

FIGURE 4. The profiles of temperature, relative humidity, and solar intensity

The temperature, relative humidity, and solar intensity data obtained from measurements during the drying of cassava starch using hybrid solar dryer at 60 °C are shown in Figure 4. It can be seen that the ambient temperature ranged from 29 to 32 °C. The temperature of dryer outlet ranged from 48 to 53 °C and dryer temperature ranged from 52 to 57 °C. This implies that some heat were used to dry the cassava starch. The solar intensities are varied between 600 to 1200 W/m^2. The maximum solar intensity recorded is 1138.5 W/m^2 during drying at 12.00. The average solar intensity on each tray is 1031 W/m^2. However, according to a research, the recorded average solar radiation in Semarang is 1536.63 W/m^2. This might be caused by different measurement time and geographical position.[16] The ambient RH recorded in this experiment is 74.63%. The recorded RH inside the dryer varied from 18% to 23%. It can be seen from Figure 4 that the RH profile is inversely proportional to dryer temperature. This phenomenon is similar to other researches about solar dryer.[14,17] As the dryer temperature increase, more water will be evaporated from cassava starch. This evaporation causes the reduction of the moisture content of cassava starch, which in turn also reduce the value of relative humidity inside the dryer.[17]

Analysis of Moisture Content Curve

The initial moisture content of wet cassava starch used in this experiment is 39.93% wet basis. The drying process was performed for three hours because it was estimated that the safe moisture content of 15% can be reached in that range of time.[5] This is supported by similar study about cassava starch drying which states that cassava starch's moisture content will reach 15% after drying for approximately 100-200 minutes.[11] Figure 5 shows the moisture content curve versus time on cassava starch drying at the tray 1, with the drying temperature of 40-60 ºC.

It can be seen from the graph that there is a moisture reduction as drying time increases. The final moisture content of cassava starch dried at drying temperature of 40, 50, and 60 ºC are 23%, 19.5%, and 14.8%, respectively. Based on this results, drying at 60 ºC gave the best result, according to the SNI standard (15% w.b). It is also shown that the moisture content reduction at the initial phase is faster compared to the final phase. This also implies that the cassava starch drying falls under the falling rate period, which means the drying rate gets slower as drying time increases, and eventually will reach a constant value in which the moisture reduction in the system is no longer noticeable. This is common in food products and crops, whose generally only have the falling rate period during its drying process. The higher the drying temperature, moisture reduction becomes faster. This happens because the drying air is less humid, making it easier to take more water from the cassava starch during the drying process.[18]

Figure 6 shows the moisture content curve versus time at different trays, during drying at 60 °C. It can be known that moisture reduction at the first (the bottom tray) is the fastest, followed by second (middle tray) and third tray (top tray). The heated drying air flows to the first tray first, then flows upwards to the second tray, and then to the top tray. Therefore, the first tray will be the first to receive the heat from the drying air. The drying air that flows upwards to the second and third tray was cooler and contained more water vapor compared to the heated drying air that entered the first tray. The moisture reduction of the second tray and the third tray were slower compared to the first tray. Other than that, since the top tray is located near the exhaust (placed at the top of the dryer), it has more contact with the external colder air, compared to the middle or the bottom tray.[19] This explains why the moisture reduction on the top tray is the slowest.

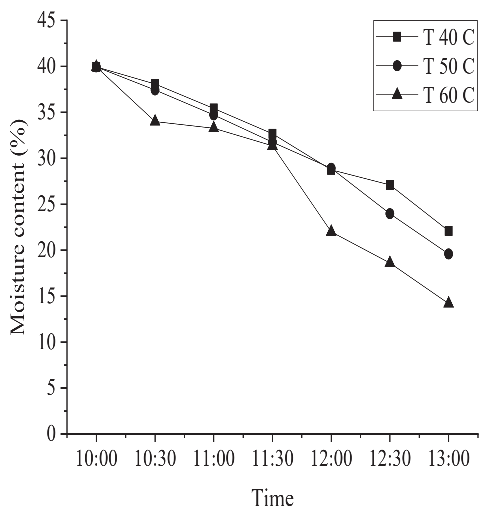

FIGURE 5. Moisture content versus time curve at the first tray on different drying temperatures

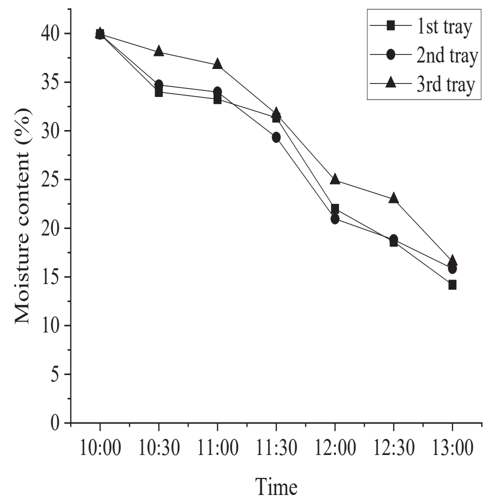

FIGURE 6. Moisture content versus time curve at different trays during drying at 60 °C

Drying Rate Analysis

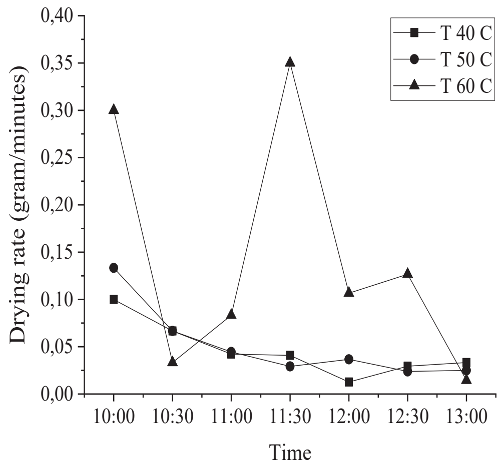

FIGURE 7. Drying rate curve of cassava starch at different temperatures on the first tray

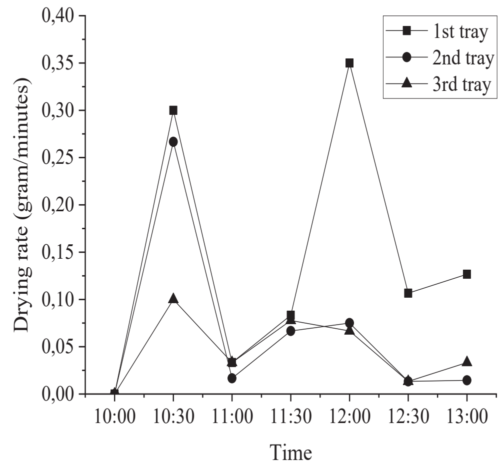

FIGURE 8. Drying rate curve of cassava starch at different trays during drying at 60 °C

Drying rate is defined as the amount of water evaporated at a certain amount of time. Figure 7 shows the drying rate of cassava starch dried in hybrid solar dryer, at the first tray. From the figure 7, it is shown that the drying rate cassava starch at the temperatures of 40, 50, and 60 ºC during the first 30 minutes were 0.014 gram/minutes, 0.025 gram/minutes, and 0.03 gram/minutes, respectively. The higher temperature will lead to faster drying rate, because there will be more water evaporated, as explained in previous section. It can also be seen that the drying rate is fast at the initial phase of the drying, then gradually decreasing until it reaches constant value.[20] This is because at the initial phase, the moisture content at the cassava starch was still high. As the drying process continues, the moisutre content becomes fewer and fewer, thus the moisture uptake by drying air becomes lower. This continues until the drying rate becomes constant, or in other words, until there are no significant moisture reduction anymore.[18] The reduction of drying rate can be seen more clearly if the drying time is further extended.[11]

Figure 8 shows the drying rate of cassava starch drying at different trays, at 60 °C. It can be seen that drying rate at the first (bottom) tray was the fastest, followed by the second (middle) tray and then the third (top) tray. This phenomenon happens because hot drying air that flows to the trays will take the moisture from the first tray, then flows upwards to the second and third tray.[21] This will slow down the drying process on the second and third tray, because the drying air became humid and less effective to be used as a heating medium. From the graph, the drying rate at the second tray is nearly equal to the third tray, although during the end of the drying process, drying rate at the third tray is higher than the second tray. On other solar drying research that employs similar solar dryer design, it is stated that the top tray captures more solar radiation than the middle and the bottom tray. The additional heat increased the temperature in the tray, which in turn speeds up the drying rate.[22]

The Relation Between Drying Rate and Moisture Content

Figure 9 shows the curve of moisture content versus drying rate. It is shown that drying rates were high when the moisture content is still high, i.e. during the initial phase of the drying. As the moisture content reduced, the drying rate decreased. The same results were also found on researches about forced-convection solar dryer for curcuma,[23] heat pump drying on grated carrot,[24] and seaweed drying using convective air drier.[25] The curve's trend indicates that the constant rate period happened in a very short time, and drying process mostly happened in the falling rate period.[26].

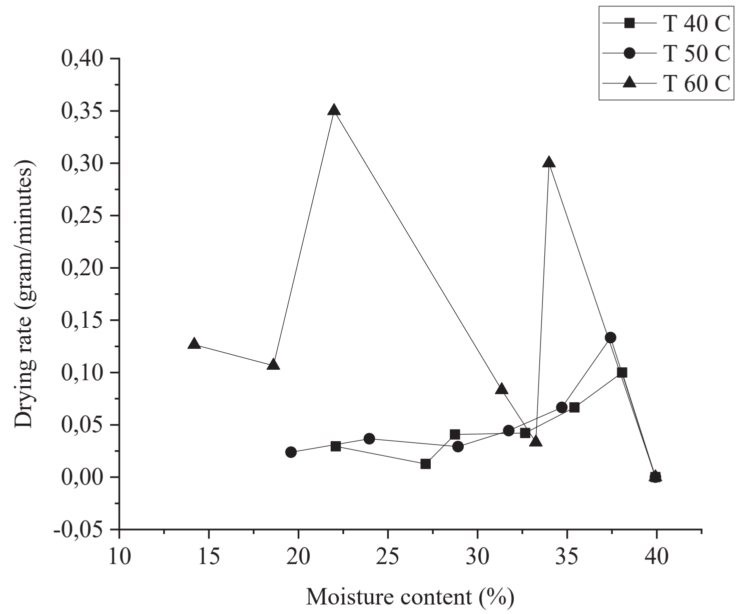

FIGURE 9. Moisture content versus drying rate at different temperatures

Effectivity Factor Analysis

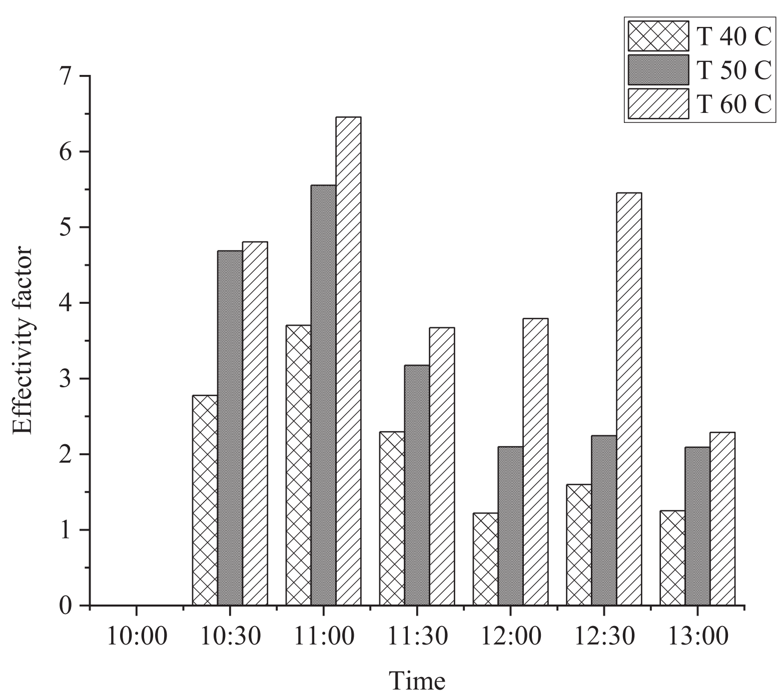

FIGURE 10. Effectivity factor on the first tray at different drying temperatures

The effectivity of hybrid solar dryer compared to open sun drying can be determined by dividing the drying rate of hybrid solar dryer and drying rate of open sun drying. Figure 10 shows the curve of effectivity factor versus drying time. It can be seen from the graph that the highest value of effectivity factor is found during drying at 11.00, with the effectivity values at 40, 50, and 60 ^{o}C are 3.7, 5.5, and 6.4, respectively. This phenomenon might happen because during the initial phase of the drying, there are still a lot of water present in cassava starch, thus making the drying process using hybrid solar dryer much efficient and increase the effectivity factor. It can also be seen that drying at 60 ^{o}C gave the highest value of effectivity factor. This is because the drying rate at 60 ^{o}C is much faster compared to both open sun drying and drying with hybrid solar dryer at 40 and 50 ^{o}C. Other than that, the value of effectivity factor in this experiment is always higher than one. The effectivity factor will be less than one during the end of the drying. This indicates that cassava starch drying using hybrid solar dryer is more efficient than open sun drying.[15]

CONCLUSIONS

A study about performance of hybrid solar dryer with LPG on cassava starch has been performed. Drying experiments were carried out to obtain the required data for several analysis, namely temperature, relative humidity, and solar intensity profile analysis, moisture content analysis, drying rate analysis, drying rate versus moisture content analysis and analysis of the dryer's effectivity factor.The profiles of temperature, relative humidity, and solar intensity are very dependant on weather condition, geographical condition and location, and measurement time. Higher drying temperature will lead to faster moisture reduction and the moisture reduction was at its fastest during the initial phase of drying. It is found that from three different temperatures used, only drying at 60 °C that meets the requirements of cassava starch's safe moisture content limit according to the SNI. Higher drying temperature will lead to faster drying rate. Drying rate was fast at the initial phase of the drying, then gradually decreased as drying time increased, until it reached a constant value. The fastest moisture reduction happened at the first tray, followed by the second tray and the third tray. Drying rate is found to be high at high level of moisture content, then decreased gradually as moisture content decreased. The constant rate period happens very quickly and cassava starch drying using hybrid solar dryer mostly took place at the falling rate period. From comparison wih open sun drying, hybrid solar dryer was found to be more effective, with the highest effectivity factor value recorded was 6.4

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REFERENCES

1. FAO, *Crops,* Accessed from http://www.fao.org/faostat/en/#data/QC, August 10th, 2019.
2. A. Midilli and H. Kucuk, Energy Convers. Manag. **44**, 1111-1122 (2003).
3. D.W. Kurniawan and T. N. S. Sulaiman, *Teknologi Sediaan Farmasi* (Graha Ilmu, Yogyakarta, 2010).
4. A. A. El-Sebaii and S. M. Shalaby, Renew Sust Energ Rev **16**, 37-43 (2012).
5. Badan Standarisasi Nasional, *SNI 3451-2011: Tapioka* (2011).
6. O. U. Dairo, A. A. Aderinlewo, O. J. Adeosun, I. A. Ola and T. Salaudeen, *Acta Technol. Agric.* **18**, 102-107 (2015).
7. K. Strom, "Product quality in solar dried carrots and onions," Master's Thesis, Norwegian University of life Sciences, 2011
8. M. Mohanraj and P. Chandrasekar, J. Eng. Sci. Technol **4**, 305-314 (2009).
9. R. Khama, F. Aissani and R. Alkama, J. Eng. Sci. Technol **11**, 1263-1281 (2016).
10. S. Aichayawanich, M. Nopharatana, A. Nopharatana and W. Songkasiri, Carbohydr. Polym. **84**, 292-298 (2011).
11. N. A. Aviara, L. N. Onuoha, O. E. Falola and J. C. Igbeka, Energy **73**, 809-817 (2014).
12. P. Pornpraipech, M. Khusakul, R. Singklin, P. Sarabhorn and C. Areepraser, ANRES **51**, 402-409 (2017).
13. AOAC, *Official Methods of Analysis***.** 18th ed (Association of Official Analytical Chemists, Arlington, 2005).

14. S. Suherman, M. Djaeni, D. H. Wardhani, M. D. Ramadhan and M. N. B. Fahreza, “Performance analysis of solar tray dryer for cassava starch” in *The 24th Regional Symposium on Chemical Engineering (RSCE 2017)*, MATEC Web of Conferences 05008 (EDP Sciences – Web of Conferences, Les Ulis, 2018).
15. D. Saravanan, V. H. Wilson and S. Kumarasamy, FU Mech. Eng **12**, 277-288 (2014).
16. M. R. Yuliyatmaja, “Study of the sun irradiation time and solar intensity to the apparent movement of sun suring the solstice period in Semarang (A case study of Meteorological, Climatological, and Geophysical Agency and Geophysics Station of Semarang on June and September, from 2005 until 2007),” Undergraduate Thesis, Universitas Negeri Semarang, 2005
17. N. Rathore and N. L. Panwar, Clean Technol. Environ Policy **13**, 125-132 (2011).
18. A. S. Mujumdar and E. Tsotsas, *Modern drying technology, volume 4: Energy savings* (Wiley-VCH, Weinheim, 2011).
19. D. Gudiño-Ayala and A. Calderón-Topete, Energy Procedia, **57**, 1642-1650 (2014).
20. S. Suherman, N. F. Azaria and S. Karami, “Performance study of fluidized bed dryer with immersed heater for paddy drying” in *IOP Conference Series: Materials Science and Engineering,* IOP Conference Series 316. (IOP Publishing, 2018) 012026.
21. T. A. Yassen and H. H. Al-Kayiem, Solar Energy **134,** 284-293 (2016).
22. E. Baniasadi, S. Ranjbar and O. Boostanipour, Renew Energ. **112**, 143-150 (2017).
23. D. V. Lakshmi, P. Muthukumar, J. P. Ekka, P. K. Nayak and A. Layek, *J. Food Process Eng.* **13045**, 1-12 (2019)
24. M. Aktaş, A. Khanlari, A. Amini and S. Şevik, Energ. Convers. Manage **132**, 327-338 (2017).
25. R. Sarbatly, T. Wong, A. Bono and D. Krishnaiah, Int. J. Food Eng. **6**, article 7 (2010).
26. A. Fudholi, M. Y. Othman, M. H. Ruslan, M. Yahya, A. Zaharim and K. Sopian, “The Effects of Drying Air Temperature and Humidity on the Drying Kinetics of Seaweed” in *GEMESED'11 Proceedings of the 4th WSEAS international conference on Energy and development - environment – biomedicine*, Recent Researches in Geography, Geology, Energy, Environment and Biomedicine (2011), pp. 129-133.