IOP Conference Series: Earth and Environmental Science

Development of the solar-energized foodstuff drying system for urban communities

To cite this article: H Susanto *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **490** 012009

Development of the solar-energized foodstuff drying system for urban communities

H Susanto[1,2], R H Setyobudi[2,3*], Y Chan[1], S M Nur[2], E Yandri[2], J Burlakovs[4], H Asbanu[1], Y A Nugroho[5], and Y Jani[6]

[1]Department of Mechanical Engineering, Darma Persada University, Jl. Taman Malaka Selatan No.22, Jakarta 13450, Indonesia
[2]Graduate School of Renewable Energy, Darma Persada University, Jakarta, Indonesia
[3]Department of Agriculture Science, Postgraduate Program, University of Muhammadiyah Malang, Jl. Raya Tlogomas No.246, Malang 65145, Indonesia
[4]Department of Water Management, Estonian University of Life Sciences, Friedrich Reinhold Kreutzwaldi la, 51014 Tartu, Estonia
[5]Division of Plant Production and Biotechnology, PT SMART, Tbk, Bogor 16810, Indonesia
[6]Department of Biology and Environmental Science, Linnaeus University, Stuvaregatan 4, SE-392 31 Kalmar, Sweden

*Corresponding author: roy_hendroko@hotmail.com

Abstract. Urban in Indonesia, is no longer limited as a center of community settlement. Now the city also functions as a center of government, a central hierarchy, and a center of economic growth. As a logical consequence of the role of cities as a center of growth and economy, urban contributions to national economic growth are increasing. To overcome this problem, a portable conveyor of solar-energized drying system was designed. With the portable conveyor of solar-energized drying system, the dryer will be easily moved and flexible to use. The advantage of portable conveyor of solar-energized drying system is the drying process could be done continuously with a little human power. Therefore, this portable conveyor of solar-energized drying system is designed to use renewable energy sources. To examine the portable conveyor of solar-energized drying system, the foodstuff was used for a testing of ingredients. The portable conveyor of solar-energized drying system testing show that the amount of water content in the foodstuff reduced, the drying rate accelerate. In addition, the amount of heat energy needed for the drying process also reduced. Hence process of drying foodstuff more efficienct.
Keywords: Drying, economic growth, portable conveyor, renewable energy, urban.

1. Introduction

Urban in Indonesia, is no longer limited as a center of community settlement. Now the city also functions as a center of government, a central hierarchy, and a center of economic growth. As a logical consequence of the role of cities as a center of growth and economy, urban contributions to national economic growth are increasing. This growth has a big impact on the city itself. In terms of population, for example, there is a large population growth from year to year. Of course also such rapid population growth has major consequences for cities. The increase in population in the midst of increasingly limited public space, making the city increasingly lose its function as a means of comfortable settlement. The economic crisis that has hit Indonesia in recent years, has forced the city to bear an additional burden that is quite serious. Increasing urbanization from rural to urban areas, coupled with an increase in unemployment makes the problem of the city more complex. Therefore, to face these challenges and so that the economy of urban communities is increasing and improving amid increasingly fierce competition, then the innovation of developing a renewable energy-based food dryer system becomes one of the alternative solutions in solving economic problems in urban areas. Currently more and more renewable energy-based drying systems are being developed. Some developed a foodstuff drying system [1], developed a cocoa beans drying system [2], developed a wood drying system [3, 4], developed a shoe drying system [5], developed a biomass-energized drying system [6, 7], developed a cloth drying system [8], developed the radio frequency and microwave heating treatment to disinfest *kutu beras* [*Sitophilus oryzae* (Linnaeus, 1763] [9], development of building rehabilitation with dry and wet systems [10], and development of heating zone temperature control for the drying process [11]. Hence the development of a drying system using this renewable energy source, becomes a challenge and also a solution for urban communities in their efforts to improve their economy and prepare for facing increasingly fierce competition.

2. Research methodology

2.1 Research flow diagram

In this paper, the research steps are shown in the following research flow diagram in figure 1 below:

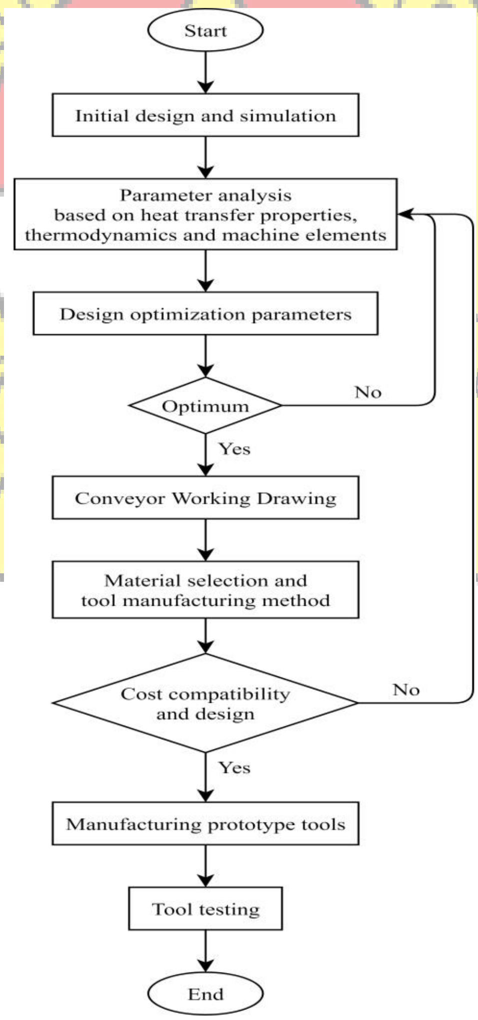
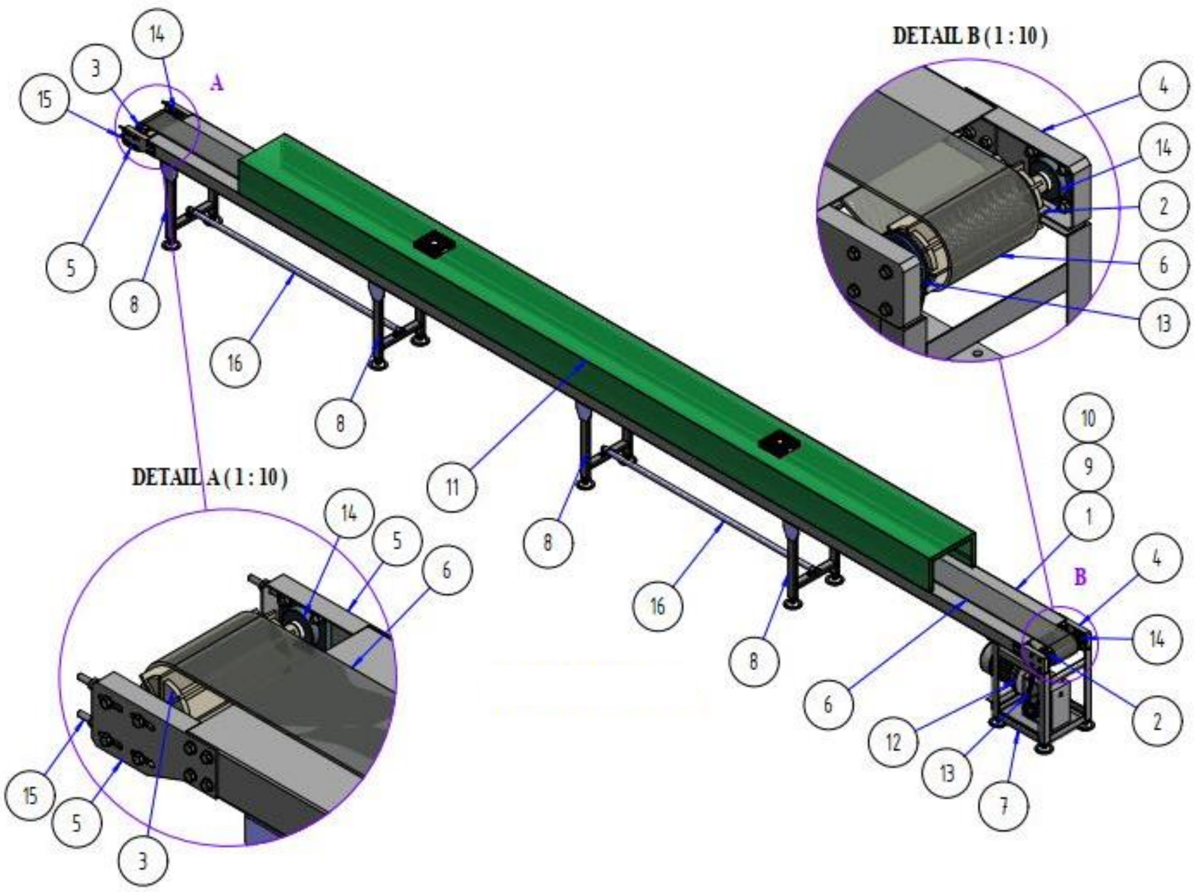


Figure 1. Research flow diagram.

IOP Conf. Series: Earth and Environmental Science **490** (2020) 012009 doi:10.1088/1755-1315/490/1/012009

2.2. Portable conveyor of solar-energized drying system

Design of the portable conveyor of solar-energized drying system to be studied can be seen in figure 2 below, the advantage of this solar-energized drying system is the drying process can take place continuously using heat from solar energy. The main components of the portable conveyor of solar-energized drying system shown as the following picture:



Drawing part list :

1. Main Frame
2. Drive Pulley
3. Tail Pulley
4. Drive Plate
5. Tail Plate
6. Wiremesh Belt
7. Drive Foot Conveyor
8. Tail Foot Conveyor
9. Heavy Duty Roller Ø60 mm × 318 mm
10. Bracket Roller
11. Oven Room
12. Drive Unit
13. Roller Chain Unit
14. UCF 205
15. Adjuster
16. Pipe Bracing

Figure 2. The portable conveyor of solar-energized drying system components.

The explanations of these components are as follows:

i. Main Frame, is the main frame of the conveyor made of 3 mm thick plate and the other components are installed.
ii. Drive Pulley, is a pulley component that deals directly with the gearbox motor and serves as the initial drive of the conveyor system.
iii. Tail Pulley, is the last pulley component (end) of the conveyor which moves following the drive pulley and serves as a place for the rotation of the wiremesh belt from the conveyor. Tail pulley is usually the starting point of the transfer of material.
iv. Drive Plate, is a component that is the base of the pillow block drive pulley holder.
v. Tail Plate, is a component that is the base of the pillow block tail pulley holder.
vi. Wiremesh Belt, is the main component that functions to carry or move goods from tail pulley to drive pulley.
vii. Drive Foot Conveyor, is a conveyor support component which is also the seat holder of the motor gearbox.
viii. Tail Foot Conveyor, is another support component of the conveyor.
ix. Heavy Duty Roller, is a return roller component whose position is below the main frame and serves to support the wiremesh belt.
x. Bracket Roller, is a component that becomes a heavy duty roller holder.
xi. Oven, is a component that is a place for drying materials, the oven wall uses polycarbonate material with a 25 mm × 25 mm hollow frame and the hot air is flowed through a heat distribution pipe outlet that comes from the burner.
xii. Drive Unit, is a gearbox motor component that functions as a conveyor drive source.
xiii. Roller Chain Unit, is a transmission component consisting of a sprocket and chain that connects the gearbox motor and drive pulley.
xiv. UCF 205, is a pillow block component that functions as a drive pulley and tail pulley holder.
xv. Adjuster, is a component that serves to regulate the tightness of the wiremesh belt.
xvi. Pipe Bracing, is a binding component of tail foot conveyor to be stable and rigid.

2.3. Working principle of the portable conveyor of solar-energized drying system

The first step in the operation of this portable conveyor of solar-energized drying system is to place foodstuff such as grain, corn, pepper, coffee, soybean, vermicelli, etc., in a container called a baking sheet. Hot air is blown into the oven room through a heat distribution pipe that is in the oven room, with a heat source coming from the burner. The heat distribution pipe in the oven room is perforated 4 mm and evenly distributed along the pipe with a distance of 150 mm between the holes. With such a hole position, the distribution of hot air will be evenly distributed and fill the oven room, hence the foodstuff carried using the conveyor when passing through the oven room will be exposed to heat and cause evaporation of water contained in the foodstuff. With this evaporation, when the foodstuff comes out of the oven room will dry out. The heat source of the portable conveyor of solar-energized drying system can be supplied from a burner uses solar-energized system. The drying rate is regulated through the conveyor speed, so that the drying process can take place optimally and evenly.

2.4. Research stages

The research activity is planned to be divided into two stages as follows:

i. The initial stage is the initial design of the portable conveyor of solar-energized drying system.
ii. The second stage is the design and manufacture of working drawings of portable conveyor of solar-energized drying system, system simulations and performance tests.

3. Mathematical equation

The rate of evaporation of foodstuff water contant in drying process is largely determined by the increase in temperature. The greater difference between the temperature of the heating medium and the dried foodstuff, the greater the speed of heat transfer into the foodstuff, hence the evaporation of water content from the foodstuff will be more and faster [2]. The higher the temperature and speed of the dryer air flow, the faster the drying process takes place. The higher the air temperature, the greater the heat energy carried by the air. Furthermore, increasingly mass of liquid is evaporated from the surface of the dried foodstuff. If the speed of the dryer air flow is higher, the faster the mass of water vapor is transferred from the foodstuff to the atmosphere [2]. The water content of the foodstuff shows the amount of water content in the weight of the foodstuff. In this case there are two methods to determine the foodstuff water content, based on wet base and dry base water content. The wet base water content in the foodstuff was calculated using the following equation:

$$MC_{wb} = \frac{W_a}{W_b}\, x\, 100\ \% \qquad (1)$$

Then calculate the dry base water content in the foodstuff using the following equation:

$$MC_{db} = \frac{100MC_{wb}}{100 - MC_{wb}} \qquad (2)$$

The drying rate can be calculated using the following equation:

$$M = \frac{M_0 - M_t}{\Delta t} \qquad (3)$$

The amount of heat used for drying can be calculated using the following equation:

$$Q = Q_1 + Q_2 + Q_3 \qquad (4)$$

Where Q_1 (sensible heat of the foodstuff) is obtained from the following equation:

$$Q_1 = m_k \,.\, c_p \,.\, (T_1 - T_0) \qquad (5)$$

Q_2 (sensible heat of the water) is the heat used to increase the temperature of the water in the foodstuff obtained from the following equation:

$$Q_2 = m_a \,.\, c_a \,.\, (T_1 - T_0) \qquad (6)$$

Q_3 (latent heat of the water evaporation) is the amount of heat used to evaporate the water from the foodstuff obtained from the following equation:

$$Q_3 = m_w \,.\, h_{fg} \qquad (7)$$

To determine the amount of heat given by hot air in the dried foodstuff, using the following equation:

$$q = \rho \,.\, V \,.\, c_u \,.\, (T_{in} - T_{out}) \qquad (8)$$

To determine the drying efficiency, using the following equation:

$$\eta = \frac{Q}{q}\, x\, 100\ \% \qquad (9)$$

where : MCwb = Wet base water content (%)
MCdb = Dry base water content (%)
Wa = The water mass in the foodstuff (kg)

Wb = The wet foodstuff mass (kg)
M = Drying rate (kg s^{-1})
M_0 = The initial mass of the dried foodstuff (kg)
M_t = The final mass of the dried foodstuff (kg)
Δt = The drying time interval (s)
Q = The amount of drying heat (kJ)
Q_1 = Sensible heat of the foodstuff (kJ)
Q_2 = Sensible heat of the water (kJ)
Q_3 = Latent heat of the water evaporation (kJ)
q = Heat received by the foodstuff from the air dryer (kJ)
m_k = The dry foodstuff mass (kg)
m_a = The water mass (kg)
m_w = The mass of the water evaporated (kg)
c_p = Specific heat of the foodstuff (J kg^{-1} $°C^{-1}$)
c_a = Specific heat of the water (J kg^{-1} $°C^{-1}$)
c_u = Specific heat of the air (J kg^{-1} $°C^{-1}$)
h_{fg} = Latent heat of the water evaporation (J kg^{-1} $°C^{-1}$)
ρ = Density of the dried foodstuff (kg m^{-3})
V = Volume of the drying chamber (m^3)
T_0 = Initial temperature of the foodstuff (°C)
T_1 = Final temperature of the foodstuff (°C)
T_{in} = The burner inlet temperature (°C)
T_{out} = The burner outlet temperature (°C)
η = The drying efficiency (%)

4 Result and discussion

4.1. Calculation and analysis of drying process on the portable conveyor of solar-enegized drying system

The drying process on the portable conveyor of solar-energized drying system will be calculated using Autodesk CFD Motion software [12]. In the analysis process using Autodesk CFD Motion software, data are obtained as shown in table 1.

Table 1. The analysis results using Autodesk CFD Motion software.

No	Parameters	Value	Unit
1	Total mass flow in	0.087	kg s^{-1}
2	Total volume flow in	0.087	m^3 s^{-1}
3	Total mass flow out	0.122	kg s^{-1}
4	Total volume flow out	4.82×10^{-3}	m^3 s^{-1}
5	Heat transfer from air to wall	628.4	W
6	Total power of heat transfer	35 168	W
7	Inlet temperature (T_{in})	76.6	ºC
8	Outlet temperature (T_{out})	51.2	ºC
9	Length of drying chamber	6	m
10	Initial foodstuff temperature (T_0)	25	ºC
11	Final foodstuff temperature (T_1)	41	ºC
12	Wet foodstuff mass (m_b)	800	g

Table 1. continue to the next page.

Table 1. Continued

No	Parameters	Value	Unit
13	Air specific heat (c_u)	1 004	J kg^{-1} ºC^{-1}
14	Water specific heat (c_a)	4 180	J kg^{-1} ºC^{-1}
15	foodstuff specific heat (c_p)	1 700	J kg^{-1} ºC^{-1}
16	Latent heat of water evaporation (h_{fg})	2 260	kJ kg^{-1}

The data in table 1 will be used as a reference to calculate the drying process and drying efficiency using equation (1) to equation (9) as shown in table 2 and table 3.

Table 2. Calculation results of drying process.

Output (rpm*)	V_c (m s^{-1})	t (s)	V (m^3)	m_a (g)	m_k (g)	MC_{wb} (%)	MC_{db} (%)	M (g s^{-1})
14	0.088	68.21	0.329	614	186	76.74	329.84	9
15	0.094	63.66	0.307	573	227	71.62	252.36	9
16	0.101	59.68	0.288	537	263	67.14	204.35	9
17	0.107	56.17	0.271	506	294	63.19	171.69	9
18	0.113	53.05	0.256	477	323	59.68	148.03	9
19	0.119	50.26	0.242	452	348	56.54	130.11	9
20	0.126	47.75	0.230	430	370	53.71	116.05	9
21	0.132	45.47	0.219	409	391	51.16	104.74	9
22	0.138	43.41	0.209	391	409	48.83	95.43	9
23	0.145	41.52	0.200	374	426	46.71	87.65	9

* Note: 1 rpm = 1/60 Hz (SI)

Table 3. Calculation results of drying process.

Output (rpm)	Q_1 (kJ)	Q_2 (kJ)	Q_3 (kJ)	Q (kJ)	Q (kJ)	η (%)
14	5.06	41.06	0.74	46.86	57.79	81.09
15	6.18	38.32	0.69	45.19	65.80	68.67
16	7.15	35.92	0.65	43.72	71.42	61.22
17	8.01	33.81	0.61	42.43	75.30	56.35
18	8.77	31.93	0.58	41.28	77.90	53.00
19	9.46	30.25	0.55	40.26	79.55	50.61
20	10.07	28.74	0.52	39.33	80.49	48.87
21	10.63	27.37	0.50	38.49	80.89	47.59
22	11.13	26.13	0.47	37.73	80.89	46.65
23	11.60	24.99	0.45	37.04	80.58	45.96

The graphs in figure 3 and figure 4 are graphs of calculation results of drying process and efficiency:

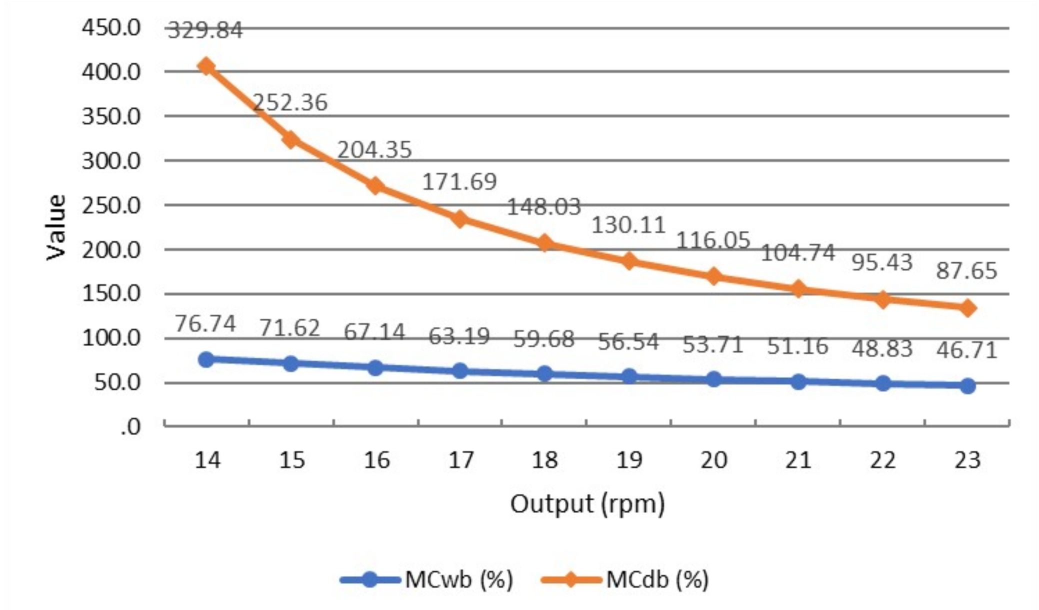


Figure 3. Graph of base water content vs motor rotation output.

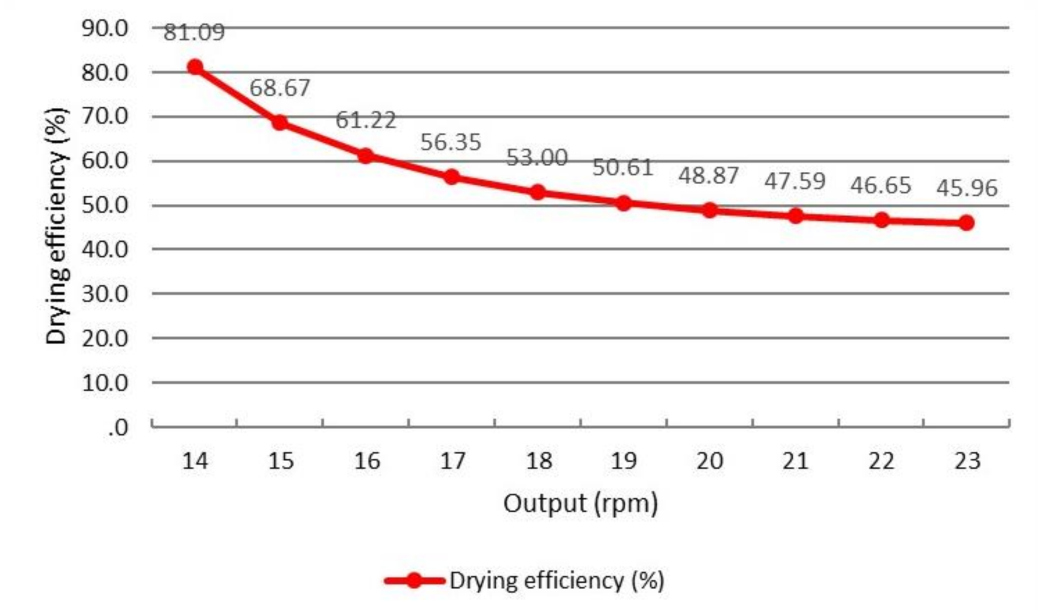


Figure 4. Graph of drying efficiency vs motor rotation output.

5 Conclusion

The results of CFD analysis can be used as a reference to calculate the foodstuff water contents, the foodstuff drying rate, the sensible heat of the foodstuff, the sensible heat of water, the latent heat of water evaporation, the amount of drying heat, the foodstuff heat given by the air and drying efficiency. When the smallest motor rotation output is 14 rpm, the drying efficiency of 81.09 % with the dried water content was 76.74 % for wet base and 329.84 % for dry base. But when the motor rotation output is 23 rpm, the drying efficiency also decreases to 45.96 % with the dried water content was 46.71 % for wet base and 87.65 % for dry base.

References

[1] Estiasih T and Ahmadi K 2011 *Teknologi pengolahan pangan* [Food Processing Technology], (Malang: Bumi Aksara) [in Bahasa Indonesia] http://pustaka.poltekkes-pdg.ac.id/index.php?p=show_detail&id=1153

[2] Sandra, Andasuryani, Santosa and Ekaputri R 2009 *Rancang bangun alat pengering tipe konveyor otomatis untuk peningkatan mutu biji kakao hasil pengeringan* [Design of Automatic Conveyor Dryers for Quality Improvement of Cocoa Beans from Drying] [National Strategic Grant Articles] (Padang: Andalas University) [in Bahasa Indonesia]. https://www.scribd.com/document/393784168/Rancang-Bangun-Alat-Pengering-Tipe-Konveyor-Otomatis-Untuk-Peningkatan-Mutu-Biji-Kakao-Hasil-Pengeringan-2009-Art

[3] Hussain T, Shamraiz M and Abrar S U 2016 Effect of temperature and vacuum on the drying rate and various parameters of wood samples, using an indigenously designed and developed vacuum drying system *International Journal of Technology* **5** 795–809 http://www.ijtech.eng.ui.ac.id/old/index.php/journal/article/view/2135

[4] Rabidin Z A, Seng G K and Abdul Wahab M J 2017 Characteristics of timbers dried using kiln drying and radio frequencyvacuum drying systems *MATEC Web of Conferences* **108**(10001) 1–5 https://www.matec-conferences.org/articles/matecconf/abs/2017/22/matecconf_icmaa2017_10001/matecconf_icmaa2017_10001.html

[5] Latifah A, Aulawi H and Ramdhani M A 2018 Design of the automatic shoe dryer *MATEC Web of Conferences* **197(**11009) 1–6 https://www.matec-conferences.org/articles/matecconf/abs/2018/56/matecconf_aasec2018_11009/matecconf_aasec2018_11009.html

[6] Atnaw S M, Faizal C K M and Oumer A J 2017 Development of solar biomass drying system *MATEC Web of Conferences* **97**(01081) 1–7 https://www.matec-conferences.org/articles/matecconf/abs/2017/11/matecconf_etic2017_01081/matecconf_etic2017_01081.html

[7] Yassen T A, Al-Kayiem H H and Habib K 2014 Evaluation of hybrid solar - biomass dryer with no load, MATEC Web of Conferences **13**(06007) 1–5 https://www.matec-conferences.org/articles/matecconf/abs/2014/04/matecconf_icper2014_06007/matecconf_icper2014_06007.html

[8] Kirar D S, Bhadoria H S and Pandey R 2016 Configuration and development of a solar cloth dryer *MATEC Web of Conferences* **57**(01019) 1–5 https://www.matec-conferences.org/articles/matecconf/abs/2016/20/matecconf_icaet2016_01019/matecconf_icaet2016_01019.html

[9] Nyzam S Z A, Rahim R A and Rahim H A 2017 Review article of radio frequency and microwave heating treatment to disinfest kutu beras in Malaysian rice *MATEC Web of Conferences* **140**(01023) 1–6 https://www.matec-conferences.org/articles/matecconf/abs/2017/54/matecconf_iceesi2017_01023/matecconf_iceesi2017_01023.html

[10] Macieira M and Mendonca P 2016 Building rehabilitation with dry and wet systems - embodied water comparison *MATEC Web of Conferences* **68**(13009) 1–7 https://www.matec-conferences.org/articles/matecconf/abs/2016/31/matecconf_iciea2016_13009/matecconf_iciea2016_13009.html

[11] Wutthithanyawat C and Srisiriwat N 2016 Temperature control of heating zone for drying process: Effect of air velocity change *MATEC Web of Conferences* **65**(03002) 1–3 https://www.matec-conferences.org/articles/matecconf/abs/2016/28/matecconf_icnscm2016_03002/matecconf_icnscm2016_03002.html

[12] Susanto H, Abdullah K, Uyun A S, Nur S M, Mahlia T M I 2018 Turbine design for low heat organic rankine cycle power generation using renewable energy sources *MATEC Web of Conferences* **164**(01012) 1-17 https://www.matec-conferences.org/articles/matecconf/abs/2018/23/matecconf_icesti2018_01012/matecconf_icesti2018_01012.html