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Utilizing the Heat Waste from Biomass Power Generation to Reduce the Moisture Content of Woodchips

Satryo Martoyoedo[1], *Syukri* Muhammad Nur[2,3], *Aep* Saepul Uyun[2,3,*], *Suherman* Suherman[4], *Ivar* Zekker[5], *Juris* Burlakovs[6], and *Barry* Mikail[7]

[1]Graduate Student of Renewable Energy, Darma Persada University, Jl. Taman Malaka Selatan No.22, Special Region of Jakarta 13450, Indonesia
[2]Graduate School of Renewable Energy, Darma Persada University, Jakarta 13450, Indonesia
[3]Center of Renewable Energy Studies, Darma Persada University, Jakarta 13450, Indonesia
[4]Department of Chemical Engineering, Faculty of Engineering, University of Diponegoro, Jl. Prof. Sudarto No.13, Semarang 50275, Central Java, Indonesia
[5]Institute of Chemistry, University of Tartu, Ravila 14a, 50411 Tartu, Estonia
[6]The Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Wybickiego 7, 31-261 Kraków, Poland
[7]Material Science and Engineering Student, Faculty of Mechanical and Aerospace, Institut Teknologi Bandung, Jl. Ganesha 10, Bandung 40132, Indonesia

Abstract. This paper is to study the drying method to reduce the moisture content (MC) of the woodchip. The methods used are to utilize the heat from solar and waste heat from the Biomass Power Plant (BioPP). By using a 250 °C heat waste from the BioPP, and stirring on the woodchip inside the drying equipment, the results obtained to reduce the MC from more than 40 % to MC around 20 % will take 2 h and 4 h faster than that which was not done on woodchips. Reducing MC from 40 % to 20 % will save 25.44 % on the woodchip consumption for combustion in the boiler of the BioPP. An analysis related to MC, CV, and woodchip consumption in generating electricity is also carried out. When MC is 26.70 %, the CV is 13.5 GJ T^{-1}, and the woodchip consumption becomes 4.62 T h^{-1} and 1.31 T MWh^{-1}, the energy produced is 764.7 kWh T^{-1}. When the MC is higher, 47.68 %, causing the CV to become 9.8 GJ T^{-1}, it is found that the consumption of the woodchips becomes 6.41 T h^{-1} and 1.81 T MWh^{-1}, the energy produced is 551.3 kWh T^{-1}.

Keywords: Biomass drying, boiler efficiency, heat waste utilization, renewable energy, woody biomass.

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[*] Corresponding author: aepsuyun@gmail.com

1 Introduction

The Conference of the Parties (COP)-26, which has already been held in Glasgow at the end of 2021, has a very ambitious target compared to the Paris Agreement (COP-21) [1]. The increase in global temperature needs to be limited to 1.5 °C through the world's carbon emission reduction scheme by 2030 and the achievement of Net Zero Emissions (NZE) by 2050 [2, 3]. One way to reduce carbon emissions is by replacing energy sources from fossils with Renewable Energy (RE) [4–6].

Based on The Indonesia National Energy Policy, the target of renewable energy in the energy mix is 23 % in 2025 and increase to 31 % in 2050. In 2021, the Ministry of Energy and Mineral Resources – Republic of Indonesia mentioned that the potency of Renewable Energy (consisting of Ocean Energy, Geothermal, Bioenergy, Wind, Hydro, and Solar) in Indonesia is 442.1 GW, where 56.9 GW will be coming from bioenergy. The realization up to 2021 for bioenergy is 1 903.5 MW (biomass plantation and waste). There are still many Renewable Energy sources in Indonesia that have not been fully utilized [7–10], including biomass. Currently, various biomass-based power generation technologies are not only used for direct combustion in boilers, either in Biomass Power Plants or co-firing at Coal Fired Power Plant but are also used for gasification [11, 12]. Biomass is a very promising source of RE in the future, most sustainable [13], and can be used as a base load in a grid. In general, the use of biomass as a source of power generation has its problems [14], where the character of biomass, especially Moisture Content (MC) and Calorific Value (CV), affects the combustion conditions in the boiler [15, 16]. High MC results in-efficiency of combustion, and it requires more effort from the operators to maintain the temperature and pressure in the boiler combustion chamber. Various attempts have been made to reduce the MC of the biomass, either by natural drying or by technological intervention.

For the needs of particleboard factories, combustion in boilers, gasification, and pyrolysis processes, the moisture content of woodchips is very important to be considered [17, 18]. Dry biomass provides considerable benefits for combustion [19], such as increased boiler efficiency, lower flue gas emissions, and improved boiler operations, compared to fuels with high moisture [20, 21]. Several attempts and methods have been carried out to reduce the MC of woodchips. MC reduction can be done by using a drying system where the heat source used can be either stand-alone or by utilizing heat from the waste of industrial activity. The most common dryer types are rotary dryers [22–25], flash dryers [26], fluidized-bed dryers [26–29], and belt dryers [30, 20]. Lee [13] in his experiment utilizing an electrical air heater found out that for reducing the MC of woodchip from 40 % to 10 % MC needed 23.0 min. With another type, the speed of screw rotation is an important parameter in screw conveyor dryers [17]. Li *et al*. [20] found out that the moisture levels can be reduced from (1.5 to 0.1 or 0.3) kg water kg fuel^{-1}, which is satisfactory for this to then be used as a fuel for combustion in the latter energy generation process, at a higher efficiency.

Based on the above review, a study on the use of heat waste from boilers as a heat source for drying woodchips, which has its character, needs to be carried out to obtain a correlation between the temperature of the heat source used, the treatment during the drying process and the expected reduction of MC. In addition, the analysis of the Biomass Power Plant (Bio PP) is carried out to find the correlation between MC, CV, power produced, and the consumption of the woodchip used.

2 Materials and methods

2.1 Material preparation

The study was elaborated based on the condition of a company located in the Merauke district, Papua, Indonesia as shown in Figure 1. The company has developed and operated a Biomass Power Plant (Bio PP) using woodchips from plantation forests as feedstock. Visits were made to the company to retrieve data relevant to the industrial activity of wood chip drying, measurement of the moisture content and calorific value of the woodchip, and the activity of the Bio PP.

Fig. 1. Site location of Bio PP in Merauke district, Papua, Indonesia.

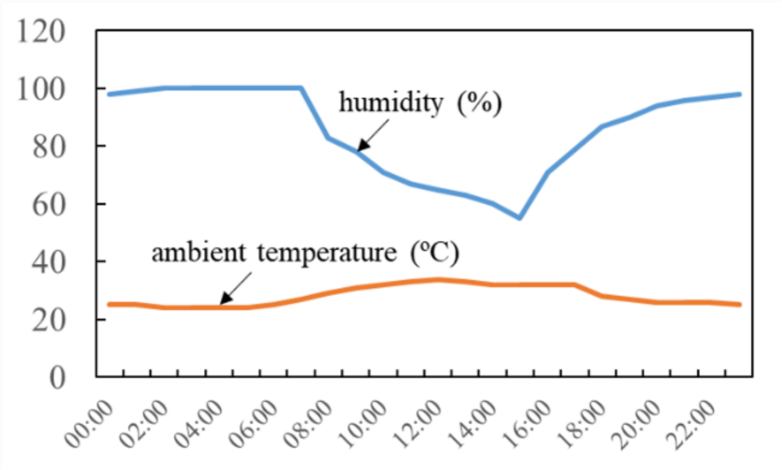

Fig. 2. Humidity and ambient temperature.

The raw biomass material comes from industrial forest plantations with species such as *Acacia crassicarpa* A. Cunn. ex Benth., *Eucaluyptus pellita* F. Muell, and *Meulaluca* sp in the form of logs. The distance from the forest concession to the location of the biomass power plant is around 10 km to 60 km. Delivery times must be well managed, especially since only logging roads are impassable when it rains. This area has 7 mo of the rainy season (November to May) and 5 mo of the dry season (June to October) with humidity of 60 % to 100 % and ambient temperature from 23 °C to 35 °C as shown in Figure 2.

Fig. 3. Process flow diagram of feedstock from log to woodchip.

In the Bio PP area, the logs are stacked in the log yard, as shown in Figure 3, and then shifted to the chip mill to be chipped by the chipper machine. The woodchips were stored in the log yard and then moved to the shelter building, and as needed, it is delivered to the boiler silo through the infeed conveyor. It was found that the capacity of the boiler silo is 60 m^3.

2.2 Chipper machine

The Bio PP has two lines of chipper machines with a capacity of 19 T h^{-1} and 20 T h^{-1}. The chipper machine is from Sweden with the brand Bruks Klockner (Table 1). The chippers are designed for chipping slabs, edgings, reject boards, cants, lily pads, veneer, small round wood, or material with an equivalent solid diameter. The wood log will be transported from forestry to the Bio PP and will be unloaded at the log yard in the Bio PP area before being processed into the chipper machine. The length of the wood log is 2 800 mm, with a diameter of 250 mm. The size of the woodchip is a minimum of (25 × 25 × 4) mm to (40 × 40 × 5) mm. The woodchip is laying in the chipyard with a volume of around 3 400 t in the open air and will be carried to the Woodchip Shelter Building (WSB). The volume of woodchip inside the WSB is 3 700 t.

Table 1. Disc chipper bruks klockner 2 100 M and 2 000 M.

Technical specification			
1	Machine type	**2 000 M**	**2 100 M**
2	Infeed opening [mm]	500 × 350	585 × 350
3	Max round wood diameter [mm]	225	250
4	Normal chipper disc [rad s^{-1}]	530	450
5	Motor size [kW]	315	315
6	Capacity [T h^{-1}]	19	20
7	Chipper knives diameter [mm]	2 000	2 000
8	Disc speed [rad s^{-1}]	450	450
9	Nos of knives [pcs]	6	7

2.3 Experiment set up

2.3.1 *Moisture content and calorific value measurement*

The MC of the woodchips is measured by using moisture meter AS 971. To measure the calorific value, the study used a bomb calorimeter PARR 6 200 with reference method:

ASTM D5865-04. Tools and material used: sample woodchip, LPG, bomb calorimeter, analytical balance, watch glass, cutter, mortar, spatula, and fuse wire.

2.4 Drying the woodchips

2.4.1 Natural Drying Method (NDM)

For the Natural Drying Method (NDM), after the chipping process, the moisture content of the woodchips is measured and recorded. The woodchips will be placed in secure storage. Then, the moisture content of the woodchips will be measured every 7 d to find out the reduction of the MC, for up to 28 d.

2.4.2 Drying Utilizing Heat Waste (DHW)

(i) DHW NT

This method is by utilizing the heat waste from the boiler for the drying process. The temperature of the heat waste, 250 °C, is flowed into the cylinder drum where the woodchips are placed. The volume of woodchips inside the drum is around 0.15 m^3. The length of the drum is 1 800 mm, and the diameter is 590 mm. The initial MC of the woodchips is recorded and then measured every hour, without any treatment of the materials. The study lasted for 3 d, carried out during the day (from 09.00 am to 03.00 pm) and at night (09.00 pm to 03.00 am). Figure 4 shows the diagram of DHW.

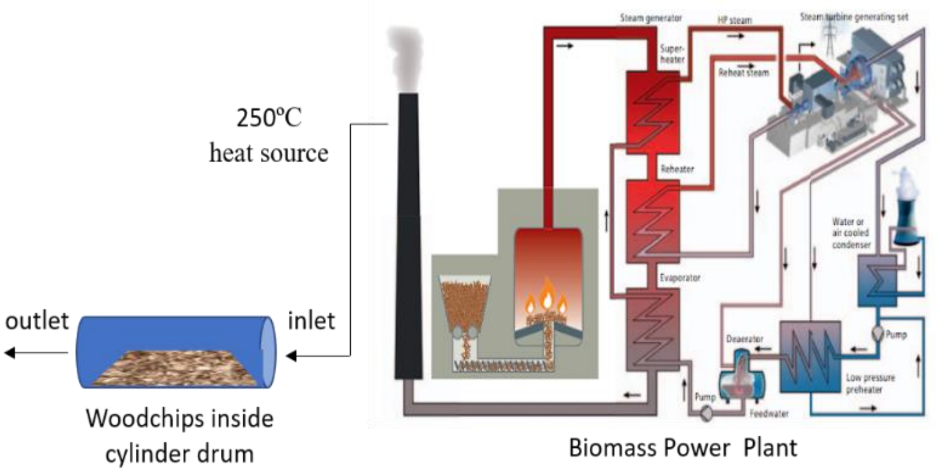

Fig.4. The process of woodchips drying utilizes the heat waste from the biomass power plant.

(ii) DHW WT-5

This method is almost the same as DHW NT. The difference is that the woodchips inside the drum are manually stirred every 5 min and then the MC is checked every hour.

(iii) DHW WT-15

This method is the same as DHW WT-15 but the woodchips are manually stirred every 15 min.

2.5 Consumption of woodchips

After getting the MC and CV of the woodchips to find out the woodchips consumption, the direct method [31, 32] is applied by Equation (1) :

$$W_{cph} = \frac{G_s \times (E_s - E_{bfw})}{B_{eff} \times LHV} \tag{1}$$

Where,
W_{cph} = Fuel consumption (T h^{-1})
G_s = Generated steam (T h^{-1})
E_s = Enthalpy of steam (GJ T^{-1})
E_{bfw} = Enthalpy of boiler feed water (GJ T^{-1})
B_{eff} = Boiler efficiency (%)
LHV = Low heating value of fuel (GJ T^{-1})

Getting the electricity produced and the woodchip consumption in producing the electricity (kWh), can be calculated by Equation (2), Equation (3), and Equation (4):

$$E_{gen} = P_{gen} \times h \tag{2}$$

Where,
E_{gen} = Electricity produced in a certain period (kWh)
P_{gen} = The power of the electricity (kW)
h = The total hour (h)

$$W_c = \frac{\Sigma W_v}{E_{gen}} \tag{3}$$

Where,
W_c = The consumption of woodchips to produce E_{gen} (T MWh^{-1})

$$E_{pw} = E_{pet} \times F_{w^{-1}} \tag{4}$$

Where,
E_{pw} = The energy produced per woodchip consumption (kWh T^{-1})
F_w = Woodchip consumption (T)

3 Results and discussions

3.1 Moisture content and calorific value of woodchips

The measurement shows that the moisture content and the calorific value of the woodchips are closely related to each other. Figure 5 shows the correlation between moisture content, MC (%), and Calorific Value CV (GJ T^{-1}). From liner regression in Figure 5, it was found as in Equation (5):

$$CV = -0.1608\,MC + 17.797 \tag{5}$$

with an R^2 value of 0.9689.

Through the data collection from the Bio PP, it was found that when the MC is 26.70 % then the CV is 13.5 GJ T^{-1} and when the MC is 47.68 %, the CV is 9.8 GJ T^{-1}. In other words, the lower MC will have a higher CV, while the higher MC will have a lower CV.

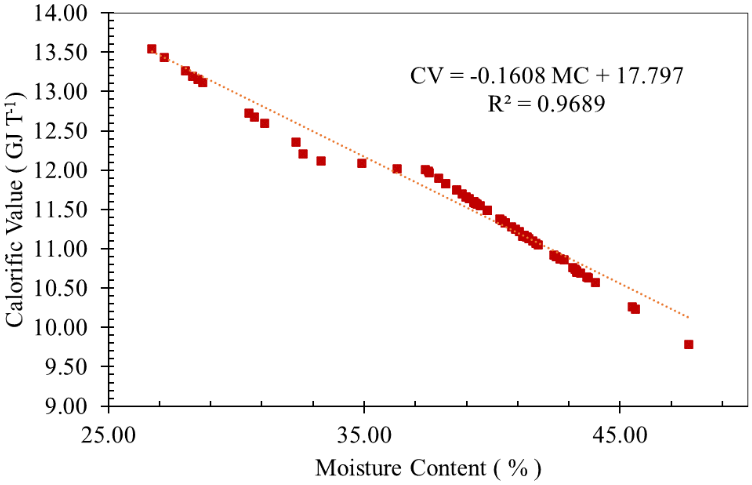

Fig. 5. Correlation between moisture content and calorific value of woodchip.

3.2 Drying the woodchips

3.2.1 Natural Drying (ND) method

Figure 6 shows the natural drying time of the woodchip. This figure shows that the MC of the fresh-cut woodchip is 54.8 %, after 7 d the MC reduces to 44.2 %, and within 28 d, the MC becomes 11.18 %. Equation (6) shows that the MC of the woodchip can be decreased by a natural drying process within the days:

$$\mathrm{MC} = -1.6649\ \mathrm{D_{nd}} + 55.064 \tag{6}$$

with an R^2 value is 0.9721. Where D_{nd} is the Day of Natural Drying in days.

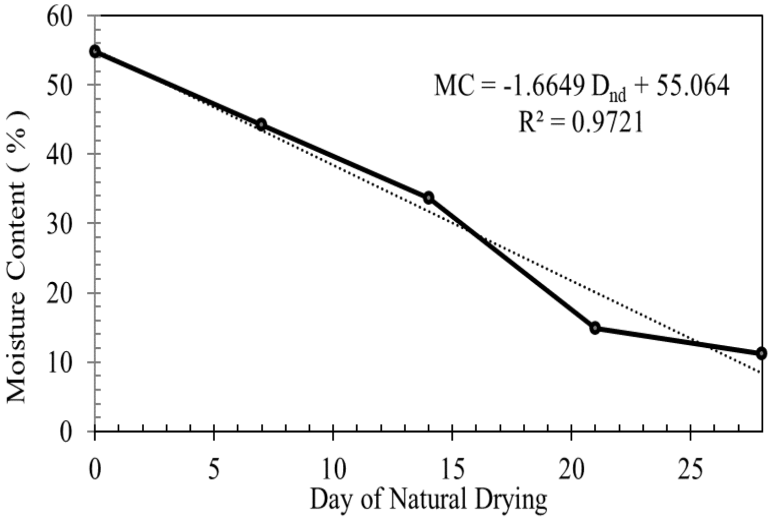

Fig. 6. Natural drying method.

3.2.2 Drying Utilizing Heat Waste (DHW) method

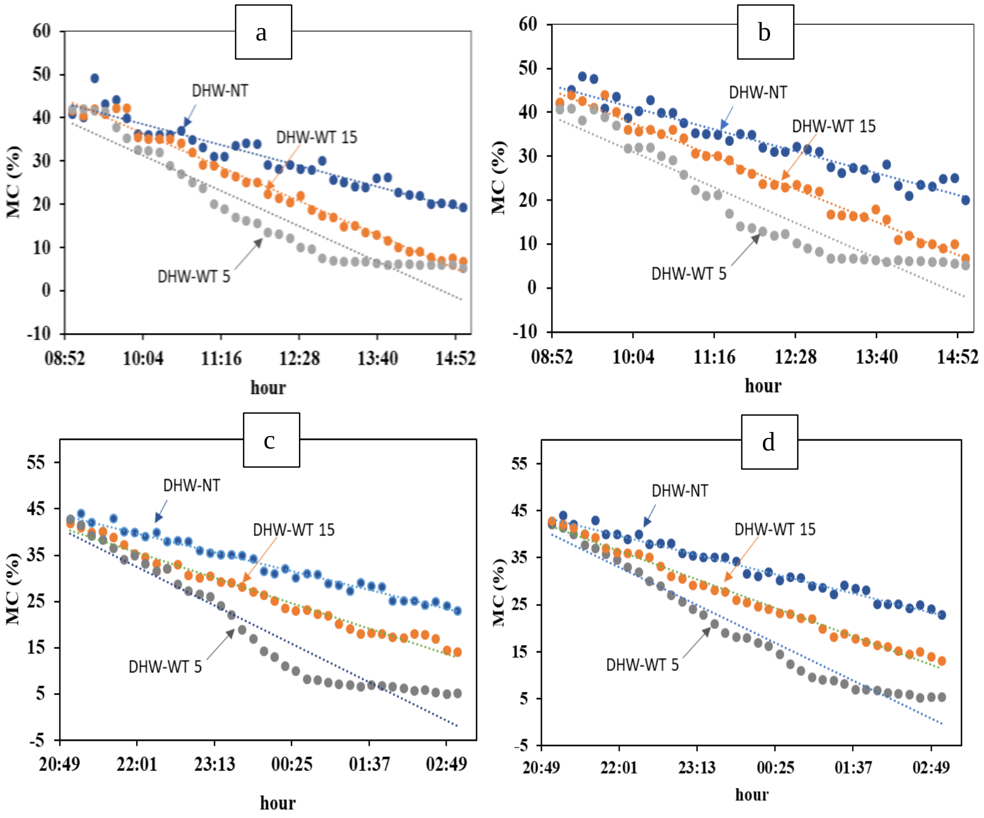

Fig. 7. Woodchips drying utilizing heat waste. (a) and (b) = at daytime, (c) and (d) = at nighttime.

The results of the drying process utilizing heat waste with three methods, Figure 7 are summarized in Table 2 and Table 3. As shown in the Table 2, in the daytime, the MC decreased from 40 % to 20 % need 6 h with DHW-NT method, 3 h with DHW-WT15, and 2 h with DHW-WT5 method. In Table 3, drying at nighttime, the MC decreased from 40 % to 20 % need more than 6 h with DHW-NT method, 4 h with DHW-WT15, and more than 2 h with DHW-WT5.

Table 2. Summary of drying woodchip in the daytime.

Time	**MC (%) in Fig. 7 (a)**			**MC (%) in Fig. 7 (b)**		
	DHW-NT	**DHW-WT15**	**DHW-WT5**	**DHW-NT**	**DHW-WT15**	**DHW-WT5**
09:00	42.00	42.20	40.70	40.80	41.70	42.10
10:00	38.80	36.10	31.70	36.20	35.50	32.50
11:00	35.30	30.10	22.30	33.20	29.10	23.70
12:00	31.90	23.70	12.90	29.10	22.30	13.40
13:00	27.50	16.80	6.80	25.60	16.90	6.90
14:00	23.30	10.90	6.40	22.70	10.10	6.20
15:00	20.10	6.80	5.10	19.30	6.70	5.20

Table 3. Summary of drying woodchip at nighttime.

Time	MC (%) in Fig. 7 (c)			MC (%) in Fig. 7 (d)		
	DHW-NT	DHW-WT15	DHW-WT5	DHW-NT	DHW-WT15	DHW-WT5
21:00	42.50	41.90	42.70	41.70	42.70	42.10
22:00	39.90	35.30	34.90	39.70	36.20	34.50
23:00	35.91	30.10	26.50	36.20	30.50	25.60
00:00	31.50	26.40	14.30	33.10	25.50	17.90
01:00	28.90	21.90	7.50	30.90	21.90	9.50
02:00	25.10	17.30	6.50	27.10	16.30	6.80
03:00	22.90	14.1	5.10	24.70	13.10	5.30

3.3 Woodchip consumption for Bio PP

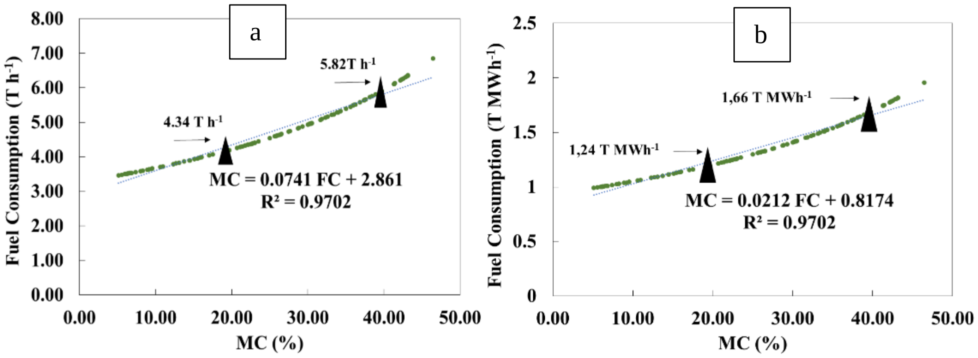

Fig. 8. Correlation between MC to woodchip consumption of combustion in boiler.

The outcomes of various techniques to lower the MC of woodchips are shown. For the next stage by applying Equation (1), Equation (2), Equation (3), and Equation (4), the woodchip consumption for the boiler (in T h^{-1} and in T MWh^{-1}) and the energy produced (in kWh and also in kWh T^{-1} woodchip) are found out. The energy produced by the Bio PP is 84 000 kWh in a day. As shown in Figure 8 (a) and Figure 8 (b), when MC is 40 %, then the woodchip consumption becomes 5.82 T h^{-1} and 1.6654 T MWh^{-1} or 600.46 kWh T^{-1}. When reducing the MC to 20 %, the woodchip consumption becomes 4.34 T h^{-1} and 1.2414 T MWh^{-1} or 805.54 kWh T^{-1}. An analysis of the power plant related to MC, CV, and woodchip consumption in generating electricity was also carried out. It shows when MC is 26.70 % then the CV is 13.5 GJ T^{-1} and it is found that the consumption of the woodchips becomes 4.62 T h^{-1} and 1.31 T MWh^{-1}, the energy produced is 764.7 kWh T^{-1}. When the MC is higher, in this case, 47.68 % causing the CV to decrease to 9.8 GJ T^{-1}, it is found that the consumption of the woodchips becomes 6.41 T h^{-1} and 1.81 T MWh^{-1}, the energy produced is 551.3 kWh T^{-1}. The results show that the lower the Moisture Content (MC), the higher the Calorific Value (CV) [33, 34], and the higher the MC, the lower the CV. The lower the MC will reduce the consumption of woodchips needed for the combustion process [35], which means it will reduce plant operating costs [36, 37].

Based on the explanation above, there are at least four things that can be discussed further regarding the use of heat waste from Bio PP to reduce MC from woodchips. First, related to the type and size of the drying equipment or dryer itself. It is important to consider this so that the drying process can run faster and also with a larger drying volume according to the needs or consumption of the woodchips for the combustion process in the boiler. Second, it turns out that the process of stirring the woodchips inside the dryer is more effective in accelerating the reduction of MC compared to the method without the process. For this reason, the dryer needed is one that can stir the woodchips. Third, related to the safety factor, namely avoiding the possibility of a fire inside the dryer. Therefore, the inclusion of a heat source in the dryer and the required heat temperature should be considered as well. Fourth, related to the magnitude of the heat temperature itself, whether the heat required is sufficient to reduce the MC to a certain value in a certain period and a certain woodchip output volume. Is additional heat still needed? That means it is necessary to consider additional facilities to overcome this. The study's findings can give an overview and comprehension of how waste heat from boilers can be used to implement energy-saving initiatives, particularly for the drying of woodchips in biomass power plants or generally in other sectors.

4 Conclusion

The Moisture Content (MC) and the Calorific Value (CV) are very closely related to each other. Higher MC affects the amount of woodchip consumption used for combustion. Therefore, it is significant to reduce the MC of the woodchips. The MC of the wet woodchips, made of wood logs and branches is about 40 %, sometimes even wetter, and it is not suitable to be used as fuel for burning. Using the Natural Drying (ND) method, utilizing ambient temperature to dry the woodchips, will need much drying area, but also its drying efficiency is very low. Furthermore, it is also affected by the weather such as rainy days, and so on. It needs 18 d to reduce MC from 54.8 % to 20 %. Experiments have shown that the Drying Utilizing Heat Waste-5 (DHW WT-5) method is the most appropriate method for reducing MC from woodchips. With an average initial value of MC above 40 %, to reduce the MC to 20 %, the ability of the DHW WT-5 method gives the following results: DHW WT-5 is 2 h faster than DHWT-15 and 4 h faster than DHW NT. And by reducing MC from 40 % to 20 %, will save 25.44 % on the use of woodchips for combustion in the boiler of this Bio PP.

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