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Heat Transfer Analysis on Coconut Shell Biomass Energy Source Heat Exchanger Design for Small-Scale Drying

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ABSTRACT: The use of fossil and solar energy sources in post-harvest by small farmers still has weaknesses. Fossil energy is increasingly expensive, while solar has the weakness of being very dependent on the weather. To overcome this, research was conducted on using coconut shell biomass as an energy source. The research was conducted on a small scale and intended for small farmers. The tool's design is appropriate so that small farmers can easily operate it. The test was conducted through heat transfer analysis of converting coconut shell biomass into thermal energy with heat exchanger tube banks. The heat exchanger tubes were placed in the combustion furnace. The test results showed that the average ambient temperature of 30°C increased to 162°C. This temperature can be utilized in various ways, such as drying. The heat generated from burning coconut shells is 341°C. Coconut shells are agricultural waste products, namely as by-products of coconuts, and are abundantly available. The use of coconut shell biomass burned directly in the furnace for the process of converting energy into thermal energy with a heat exchanger can produce a heat flow rate of 233.29 W. A post-harvest solution for small farmers can be to use coconut shell biomass through an energy conversion process with the application of a heat exchanger.

KEYWORDS: Heat transfer, biomass, coconut shell, heat exchanger, small-scale

I. INTRODUCTION

The post-harvest drying process commonly carried out by small farmers is drying in the sun. Drying is carried out to extend the shelf life of food ingredients before further processing or being sold directly to the market. Drying by drying is very dependent on the weather and is susceptible to exposure to dust or dirt due to being carried out in open areas. Sun drying in the open causes exposure to rain, dust, animals, and sometimes excessive or insufficient heat sources, as well as a long time of around 16 days, as in drying coffee to reduce water content to 13.14% [1, 2]. Overcoming long times and exposure to dirt can be done by using biomass energy sources to apply a dryer in a closed room.

Biomass is organic material derived from plants, animals, and microorganisms. Biomass sources include wood from forests, plantations, or wood waste, crops, organic waste such as fruit peels, vegetables, and animal waste, and microorganisms such as bacteria and fungi. The use of biomass is adjusted to the availability around the residence of farmers who carry out the drying process. This article discusses biomass derived from coconut waste, namely, coconut shells. This is done because coconut trees grow well around small farmers who dry coffee. Coconut shells are significantly directed at biomass, which has added value in generating income in the coconut industry [3]. The HHV of coconut shells reaches 17400 kJ/kg [4]. In Espina et al., it is explained that the calorific value of raw coconut shells is 30.79 MJ/kg, and after being torrefied at a temperature of 275°C and held for 30 minutes, it increases to 34.37 MJ/kg [5]. With this condition, its calorific value can be equated with rice husk. Rice husk has a calorific value equivalent to half the calorific value of coal and varies according to the results of several studies, namely 11-15.3 MJ/kg [6]; net calorific value 12-16 MJ/kg [7]; and 13-19 MJ/kg with an average of 18 MJ/kg [8]. The use of coconut shell biomass has the potential to replace solar drying, so that the drying process can be carried out at any time and does not depend on the weather. In addition, coconut shells are only considered as waste by the community because of their abundant availability. This condition occurs in the Lombok, Indonesia area, which produces a lot of coconuts. Coconut shell waste is only used as fuel if the availability of fossil fuels is hampered, and most of it is only piled up and then burned like garbage. The process of utilizing coconut shell biomass as an energy source, one of which is drying, is through the energy conversion process.

A heat exchanger can convert coconut shell biomass energy into thermal energy. Heat exchangers are used appropriately to suit the needs of small farmers. Using biomass in developing countries can reduce the use of firewood, increase the economic status, and energy needs of rural communities [9, 10]. Heat exchangers are applied to two fluids with different temperatures so that heat transfer occurs, and the fluids used do not experience mixing [11, 12]. Utilization of heat exchangers in reducing additional heating needs through waste heat recovery [13]. The heat transfer in the heat exchanger from higher to lower temperatures is used in drying. The drying process using heat exchangers in its application on a small scale can be in the form of vertical rack dryers or rotating types. Using artificial dryers, such as rotary dryers or rack types, can reduce post-harvest agricultural costs, such as drying. Losses in the agricultural sector caused by inappropriate drying equipment affect high energy consumption, such as tobacco, which consumes around 60% of the energy consumed by the entire production process [14, 15, 16]. Post-harvest drying through biomass energy conversion with heat exchanger applications can help small farmers optimize drying temperatures so that drying time is shorter than drying in the sun. Heat exchangers in their applications can optimize temperature through the heat transfer process. Several heat exchanger applications have been carried out to increase the heat transfer coefficient and drying. The biomass gasification system's overall heat transfer coefficient increased after the installation of counterflow and parallel flow heat exchangers [17]. Drying fish using a heat exchanger pipe arrangement to convert coconut fiber biomass can increase the environmental temperature to 41.30ºC °C, and firewood biomass produces a temperature of 40-50ºC [18, 19].

Utilization of a heat exchanger as a tool to convert coconut shell biomass to optimize environmental temperature. Environmental temperature due to solar drying is very dependent on the weather and takes a long time. Alternatively, it can be replaced with a dryer fueled by coconut shells. In addition, using coconut shells as an energy source can reduce waste and provide added value to the waste. Testing is carried out through heat transfer analysis of the heat exchanger placed in the coconut shell combustion furnace.

II. RESEARCH METHODS

The research tested coconut shell waste as an energy source for small-scale coffee bean drying. The drying process is carried out in a cylindrical chamber that rotates during the drying process. The fluid is hot air resulting from the heat transfer process between the combustion of coconut shells and the ambient air. The ambient air flows inside the heat exchanger pipes, and the heat from the combustion of coconut shells flows outside them.

The materials used are dry coconut shells, a 220 W blower with an air speed of 8 m/s. Pipes with a length of 0.2 m each and 40 pieces arranged in an aligned manner. The inner diameter of the pipe is 0.016 m, and the pipe material is copper. One single pipe 0.0508 m is placed on the side of the ambient air inlet and the outlet of the heat exchanger. The blower is used to suck in ambient air while simultaneously blowing out hot air by forced convection. The heat exchanger is placed inside the coconut shell combustion furnace. The test is as shown in the design of Figure 1. The ambient air flows through the arrangement of heat exchanger pipes in the combustion furnace, while the hot air from the combustion of coconut shells is channeled into the heat exchanger pipes. The remaining heat or smoke from the combustion of coconut shells exits through the exhaust pipe in the furnace.

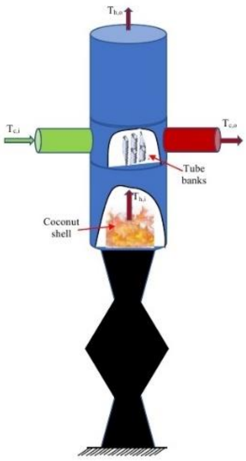

Figure 1. Test schematic

The hot air in the heat exchanger pipes flows through a single pipe in one direction out of the combustion furnace. The flame from the coconut shell must be maintained by manually adding coconut shells continuously as needed. In this study, adding coconut shells has not been carried out automatically to avoid higher costs due to the addition of biomass automation tools. This is related to users, namely small farmers who need affordable and easy-to-operate tools.

The ambient air enters through a single pipe ($T_{c,i}$), which flows through the tube banks of the heat exchanger. The air resulting from the heat transfer exits from the tube banks of the heat exchanger, which is flowed through a single pipe ($T_{c,o}$). The heat from the combustion of coconut shell biomass ($T_{h,i}$) flows into the tube banks heat exchanger and exits through the exhaust duct in the combustion furnace ($T_{h,o}$). The ambient air flows through the tube banks' heat exchanger, and the hot air from the combustion of coconut shells flows in parallel through the tubes. In this study, the calculation was carried out under ideal conditions, without considering the contamination factor that occurs in the heat exchanger. The heat transfer rate between hot and cold fluids, as shown in equation 1, with the assumption that heat transfer between the heat exchanger and the surroundings is ignored, changes in kinetic and potential energy are ignored (11).

$$q = \dot{m}_h \, C_{p,h} \left(T_{h,i} - T_{h,o}\right) \quad (1)$$

$$q = \dot{m}_c \, C_{p,c} \left(T_{c,o} - T_{c,i}\right) \quad (2)$$

$$\dot{m} = \rho \, A \, V \quad (3)$$

q expressed as the total rate of heat transfer between the hot and cold fluids (W), $\dot{m}$ is the fluid flow rate (kg/s), C_p is the heat capacity of the fluid (J/kg.K), where h represents heat, c represents cold, i represents the condition of the inlet fluid, and o represents the condition of the outlet fluid. ρ is the density (kg/m^3), A is the heat transfer surface area (m^2), and V is the fluid velocity (m/s). Logarithmic mean temperature difference (ΔT_{lm}) as in Equation 4.

$$\Delta T_{lm} = \frac{(T_{h,i}-T_{c,o})-(T_{h,o}-T_{c,i})}{\ln\frac{(T_{h,i}-T_{c,o})}{(T_{h,o}-T_{c,i})}} \tag{4}$$

Reynolds number (R_{eD}) for the hot air flow flowing into the heat exchanger tubes, as in Equation 5.

$$R_{eD} = \frac{4\dot{m}_h}{\pi D_i \mu} \tag{5}$$

D_i is the inner diameter of the heat exchanger pipes, μ is the dynamic viscosity (kg/s.m).

III. RESULTS AND DISCUSSION

The research was conducted by testing the utilization of coconut shells as an energy source through energy conversion using heat exchanger pipes. Based on the law of conservation of energy, the total rate of heat transfer of hot fluid is the same as that of cold fluid. The results of measuring the temperature of cold fluid in the form of ambient air and hot fluid in the form of fluid from burning coconut shells are presented in Table 1.

Table 1. Test results on the coconut shell energy heat exchanger design

Inlet air temperature ($T_{c,i}$)	30ºC
Outlet air temperature ($T_{c,o}$)	162ºC
Air velocity (V)	8 m/s
Inlet hot air temperature ($T_{h,i}$)	341ºC
Outlet hot air temperature ($T_{h,o}$)	50ºC
Air density (ρ)	1.093 kg/m^3
Cold air flow rate ($\dot{m}_c$)	0.00176 kg/s
Hot air flow rate ($\dot{m}_h$)	0.000783 kg/s
Heat transfer rate (q)	233.29 W
Tube arrangement	Staggered
ΔT_{lm}	72.55ºC
R_{eD} (hot air)	2,416.35

Using coconut shells as an energy source by converting energy into thermal energy using heat exchanger tubes increases the environmental temperature. The temperature distribution is shown in Figure 2.

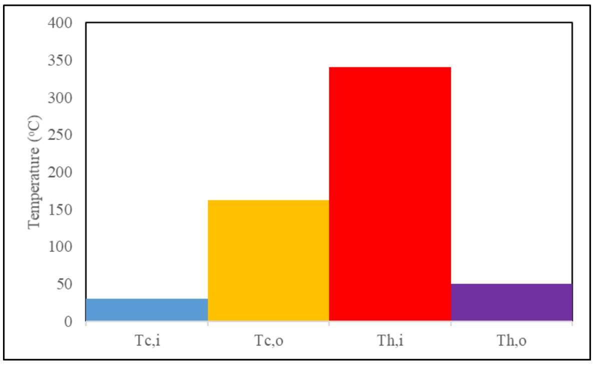

Figure 2. Temperature distribution

The average ambient temperature of 30ºC increased to an average of 162ºC. In this study, the temperature in the coconut shell burning pile was an average of 341ºC. Coconut shells have the potential to be used as a sustainable energy source as a substitute for fossil energy. Coconut shell biomass performs better than other biomass in energy and carbon content [20]. Coconut shells in Indonesia, especially in the Lombok area, are available in abundant quantities because coconut trees grow easily and abundantly. So far, only the flesh of the fruit has been used. Utilizing coconut shells as energy through the energy conversion process can provide added value to the biomass. The potential of coconut shells as bio-briquettes through effective utilization of agricultural waste and reduction of carbon emissions for a sustainable and viable energy source that offers environmental and economic benefits [21].

The temperature of the hot air coming out of the heat exchanger in the combustion furnace is the result of heat transfer from the combustion of coconut shells in the furnace to the ambient air flowing across the outside of the heat exchanger tubes. The heat generated from the combustion of coconut shells flows inside the heat exchanger tubes. The heat transfer process occurs in two fluids that have different temperatures without any mixing between the two fluids [11, 12]. Coconut shell biomass can be converted into thermal energy by transferring heat into a heat exchanger. The heat transfer occurs when coconut shell biomass is burned in a furnace to produce heat. The heat generated from biomass combustion is transferred to a fluid (such as water or air) through a heat exchanger. The heated fluid can then produce thermal energy, such as for the drying process. The advantages of utilizing heat exchangers in this study which are used to convert coconut shell biomass into thermal have the following objectives: increasing energy efficiency by transferring heat from biomass to fluid effectively; flexibility, namely heat exchangers are used for various applications, such as post-harvest drying power plants; using biomass as fuel, this process can reduce greenhouse gas emissions compared to using fossil fuels. Coconut shells can be used directly or made into briquettes. Using coconut shells as an alternative energy source provides advantages such as reducing waste or unprocessed waste in the environment, in the form of briquettes, which can be used as an alternative fuel for various effective needs [22]. Coconut shells are agricultural waste products, such as by-products of coconuts, and are abundantly available and potentially an energy source [23]. Research [23] shows that coconut shells used in boilers produce a maximum final temperature at the boiler outlet of 99ºC with a feed rate of 7.5 kg/h. If not processed, environmental problems can arise from coconut shell waste because it contains lignin, cellulose, and hemicellulose compounds that undergo pyrolysis to produce liquid smoke, charcoal, and tar [24].

Coconut shell biomass burned directly in a furnace to convert energy into thermal energy with a heat exchanger can produce a heat flow rate of 233.29 W. Logarithmic mean temperature difference (ΔT_{lm}), what happens in a heat exchanger with coconut shell energy source is 72.55ºC. For a given heat exchanger with constant area and heat transfer coefficient, the larger (ΔT_{lm}), the more heat is transferred. The logarithmic mean temperature difference (ΔT_{lm}) as shown in Figure 3.

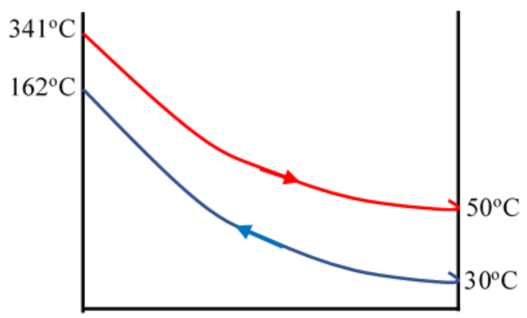

Figure 3. Logarithmic mean temperature difference (ΔT_{lm})

The Reynolds number value for hot air in the pipe is 2,416.35, which shows turbulent flow. Turbulent flow in a tube or pipe occurs at Re > 2300 [11]. Turbulent flow shows that fluid flow is uneven and characterized by changes in pressure and velocity.

Using coconut shell biomass through the energy conversion process, with the application of heat exchangers for small farmers, can be a post-harvest solution. Easy and cheap utilization in obtaining coconut shell biomass, especially in rural areas with more small farmers, is a distinct advantage. In addition, the application of appropriate tools requires only simple knowledge. Further research is needed regarding the contamination factors arising from increased operating time on heat exchangers.

CONCLUSIONS

Using coconut shell biomass as an energy source by burning it directly in a furnace integrated with heat exchanger tubes increases the ambient temperature. The average ambient temperature of 30ºC increases to 162ºC. The resulting temperature can be utilized in post-harvest processes such as drying. This can be a solution for small farmers in rural areas to speed up the drying process easily and cheaply. Easy to do because the tool is designed appropriately. Cheap because the energy source uses coconut shell biomass, which is easily found around homes where many coconut trees grow. In addition, coconut shells as waste are a by-product of coconuts. Using coconut shells can provide added value while reducing environmental pollution due to this waste.

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