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Internal Flow Heat Transfer Rate for Parallel Heat Exchanger Pipes One Pass of Rice Husk to Air

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Authors' contributions

This work was carried out in collaboration between both authors. Author IBA did the data curation, formal analysis, investigation. Author IGBS did the conceptualization, methodology, roles/writing - original draft, writing - review & editing. Both authors read and approved the final manuscript.

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ABSTRACT

The research was conducted to analyze the heat transfer rate of heat exchangers from black steel pipes with rice husk as an energy source. This can be used as a recommendation to replace solar energy in the post-harvest drying process, especially for small farmers in rural areas. Research by converting rice husk biomass into heat energy using a heat exchanger of black steel pipes arranged parallel to one air fluid flow. Heat exchanger pipes are placed inside the furnace with dimensions of 50 cm x 50 cm x 80 cm. Forced convection is applied through a fan placed in the drying chamber with a constant speed of 2 m/s. It was found that the ambient temperature increased by an average of 11.70% without adding rice husk mass during the test. The average ambient temperature (T_i) is 305.10 K and ranges from 300.60 to 307.40 K which can be increased to (T_o) 340.80 K with a range of 317.25 to 366.30 K. This temperature is the out the heat exchanger pipes that can be used for the drying process. The value of the heat transfer rate reached an average of 39.19 W with a range of 18.62-63.19 W. The pattern of distribution of heat transfer rates follows the trend of temperature

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distribution. It was found that when rice husk turns into charcoal it causes a high heat transfer rate. High heat transfer rates are needed in the drying process of a product so that the required time is shorter and optimal. In addition, rice husk biomass can be used as alternative energy because it is easy to obtain, especially in agricultural areas that grow rice.

Keywords: Heat transfer; parallel pipe; heat exchanger; rice husk energy.

1. INTRODUCTION

The utilization of rice husk biomass as a substitute for firewood is urgently needed, especially in rural areas that are still constrained to obtain fuel oil or gas. The use of firewood as energy by rural communities is still very dominant because it is easily obtained. The use of firewood has an impact on increasing tree cutting and can damage forests. Likewise, the use of the sun as an energy source still has weaknesses, especially when it is cloudy or raining causing activities to stop. As an agricultural area that mostly grows rice, the Lombok area has quite abundant rice husk biomass. In addition, rice husk is a by-product of rice because the staple food of most people is rice.

The abundant rice husk biomass is used as an energy source through the application of appropriate technology so that it can be easily applied in rural communities or small farmers. Areas that utilize rice as the main food have a very potential impact on the biomass of rice husk waste [1]. The utilization of rice husk as an energy source reduces the logging of forest wood as a result of the reduced use of firewood [2]. In addition, firewood is a scarce resource due to the degradation of forest plots and the unsustainable production of firewood [3]. The net calorific value of rice husk is 12-16 MJ/kg [4]; the heating value is close to an average of 18 MJ/kg [5]; the calorific value is equivalent to half the calorific value of coal of 11-15.3 MJ/kg [6]. Rice husk has the potential to be used as an alternative to developing energy-efficient dryers [7]. Rice husk is used as an energy source such as for the drying process is done through energy conversion. This process utilizes a heat exchanger so that the resulting temperature is optimal.

The application of heat exchangers in the heat transfer process is carried out for fluids that have different temperatures. Based on Bergman et al. that between two fluids that have different temperatures and are separated by a wall by utilizing a heat exchanger, a heat transfer process occurs [8]. Heat exchangers are used in a variety of renewable or conventional energy as they are used to complete engineering cycles [9]. Increased heat transfer and heat distribution become more homogeneous as a result of increasing the length of the heat exchanger and this helps increase energy transfer in the heat exchanger [10]. The application of heat exchangers in post-harvest such as drying processes can increase the temperature significantly through the heat transfer process from burning rice husks [11,12]. Post-harvest requires the most important and high energy consumption, namely in the form of a drying operation unit [13]. Heat transfer using a heat exchanger occurs in several forms of flow, namely parallel flow, counter flow, one fluid mixed and the other not mixed, and the two fluids mixed. In this study using air fluid that does not mix flows in the heat exchanger pipes as a cold fluid and mixed rice husk as a hot fluid outside the pipes. This model is used to determine the rate of heat transfer which can later be used in smallholder-scale food drying processes.

2. MATERIALS AND METHODS

The research was conducted to determine the rate of heat transfer in a heat exchanger composed of parallel pipes in one row and one air fluid pass. Heat exchanger pipes with a total of 7 pieces are placed in a combustion furnace with a rice husk energy source. The heat exchanger pipe material is black steel. The length and diameter of the pipe are 1 meter and 1 inch respectively. The design of the heat exchanger pipe is shown in Fig. 1.

Fig. 1. Design of a one-pass heat exchanger made of black steel, with a total of 7 pipes

Fig. 2. Research schematic

The heat exchanger pipe is placed in the combustion furnace as shown in Fig. 2. The dimensions of the furnace are 50 cm x 50 cm x 80 cm (length x width x height). Heat transfer analysis was carried out based on the fluid from the rice husk to the ambient air. Rice husk is placed outside the heat exchanger tubes by the mixed flow method, while the ambient air inside the pipes by an unmixed flow.

In this study, the environmental temperature that enters the heat exchanger pipe, the temperature outside the heat exchanger pipe, and the surface temperature of the pipe are measured. The air velocity is maintained constant at 2 m/s using an exhaust fan installed in the drying chamber to draw in ambient air. To perform a convection heat transfer analysis using several equations taken from Bergman et al. [8]. The Reynolds number (Re_D) for the flow in the tube is expressed as follows.

$$Re_D = \frac{4\dot{m}}{\pi D \mu} \quad (1)$$

D is the inside diameter of the pipe (m) and μ is the dynamic viscosity (N.s/m^2). For mass flow rates, the $\dot{m}$ (kg/s) can be expressed as the integral of the mass flux over the entire cross-section.

$$\dot{m} = \int_{A_c} \rho u(r,x) dA_c \quad (2)$$

Average velocity is used when working with the flow in a tube because the velocity varies over the entire cross-section and there is no good determination of free flow. The mass flow rate from Equation 2 through the tube is determined based on Equation 3.

$$\dot{m} = \rho u_m A_c \quad (3)$$

ρ is the density (kg/m^3), u_m is the velocity of the fluid (m/s), and A_c is the cross-sectional area of the pipe (m^2).

From Newton's law of cooling and energy balance, we can calculate the convection heat transfer rate, q_{conv} (W), and the heat transfer coefficient, h (W/m^{2}K). Calculations are made on the air side of the flow in the pipes.

$$q_{conv} = \dot{m} C_p (T_o - T_i) \quad (4)$$

$$q_{conv} = \bar{h} A_s \Delta T_{lm} \quad (5)$$

C_p is the specific heat capacity; T_o and T_i respectively inlet and outlet temperatures of the pipe; A_s = PL with P as the wet perimeter (P = πD), and L is the length of the pipe; ΔT_{lm} is the log mean temperature difference.

$$\Delta T_{lm} = \frac{\Delta T_o - \Delta T_i}{\ln(\Delta T_o / \Delta T_i)} \quad (6)$$

In this study, the pipe surface temperature (T_s) was uniform based on heat transfer from the combustion of husks to the surface of the heat exchanger pipes. Equation 6 can be described as follows.

$$\Delta T_{lm} = \frac{(T_s - T_o) - (T_s - T_i)}{\ln\frac{(T_s - T_o)}{(T_s - T_i)}} \quad (7)$$

3. RESULTS AND DISCUSSION

The heat exchanger consists of 7 black steel pipes arranged in parallel and placed at the bottom in a rice husk burning furnace and provide a temperature distribution, as shown in Fig. 3.

The heat generated from the burning of rice husks is transferred to the heat exchanger pipes and produces an average surface temperature (T_s) of 429.85 K with a range of 363-508.05 K. It was found that the pattern of the surface temperature follows the process of burning rice husks with fixed mass, that is, there was no additional rice husk mass during the test. In addition, the pattern of surface temperature (T_s) as shown in Fig. 3 is affected by the direct combustion of rice husks in the furnace. Direct burning of rice husks in the furnace is done to make it easy and produce a uniform temperature. This method is following [14] that using rice husk to produce energy through direct combustion is the most widely used because it is the domain of its use and is economically feasible. The temperature distribution pattern also follows the characteristics of rice husk, namely the combustion process begins with the evaporation of the moisture content. This is indicated by the high smoke produced from burning rice husks. The water content contained in rice husks is 6-10% [15,16]. The heat transfer that occurs from burning rice husks can increase the ambient temperature (T_i) by an average of 11.70% in the absence of additional rice husk mass during the test. The average ambient temperature (T_i) is 305.10 K and ranges from 300.60 to 307.40 K which can be increased to (T_o) 340.80 K with a range of 317.25 to 366.30 K. This temperature is the temperature outside the pipe. -pipe heat exchanger that can be used for the drying process. The temperature distribution that is at the beginning of the combustion has a pattern of increasing until it reaches a maximum and then decreasing as the mass of rice husks in the furnace decreases. The temperature pattern as shown in Fig. 3 has an impact on density (ρ) and dynamic viscosity (μ) as shown in Fig. 4.

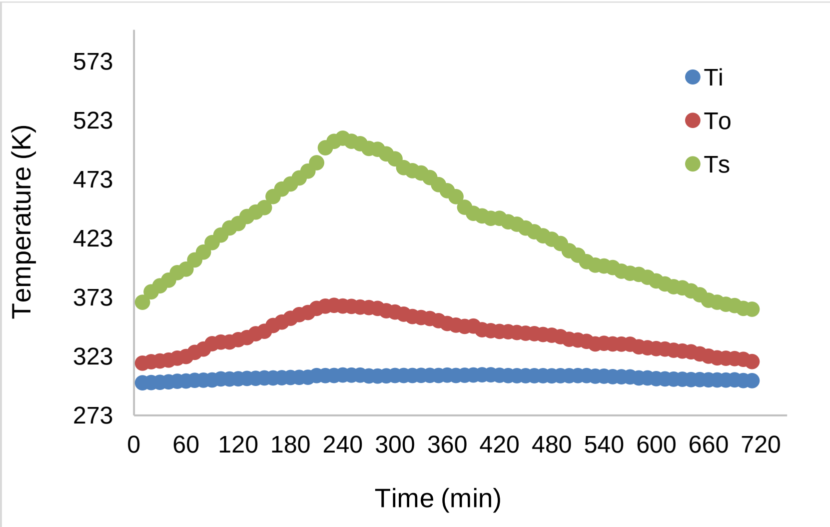

Fig. 3. Temperature of the inlet (T_i), outlet (T_o), and pipe (T_s) during the measurement time

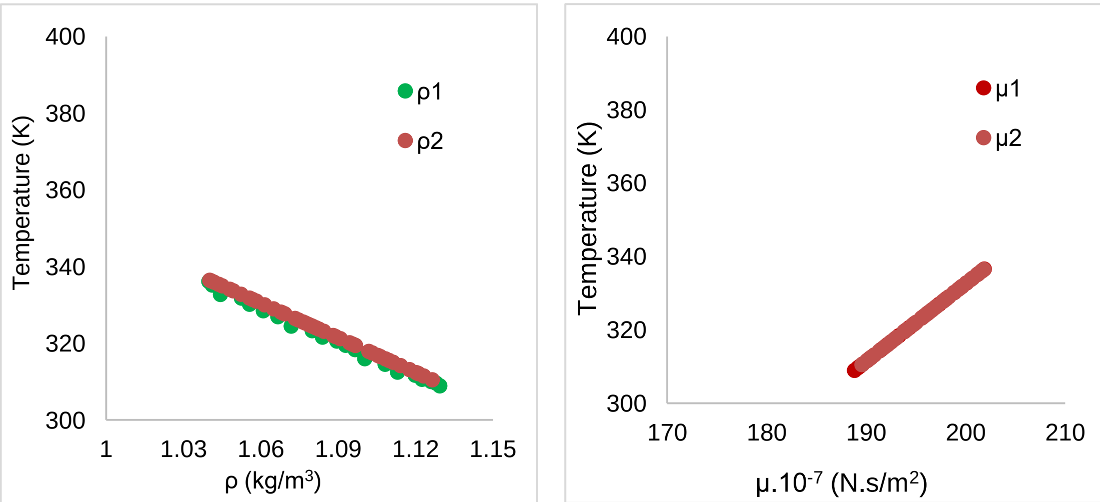

Fig. 4. Comparison of film temperature (T_f) with density (ρ) and dynamic viscosity (μ)

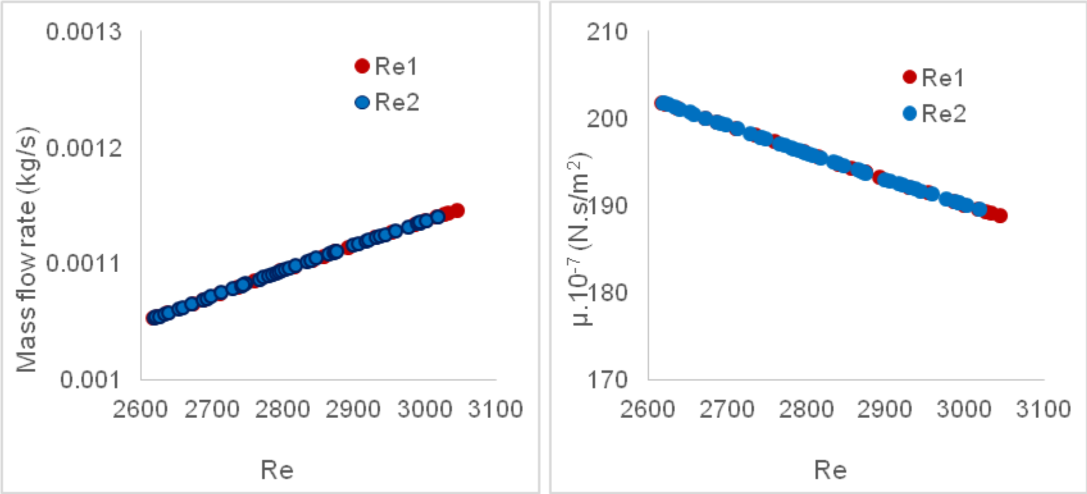

Fig. 5. Comparison of the Reynolds number (Re) with mass flow rate (ṁ) and dynamic viscosity (μ)

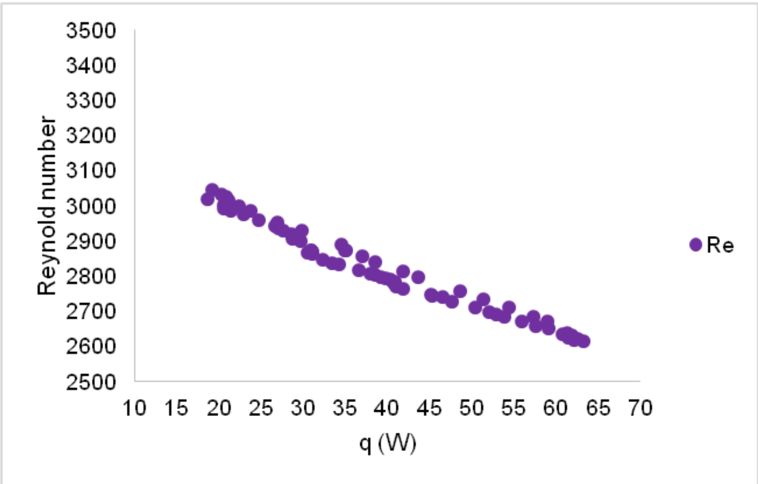

Fig. 6. The relationship between Reynolds number (Re) and heat transfer rate (q)

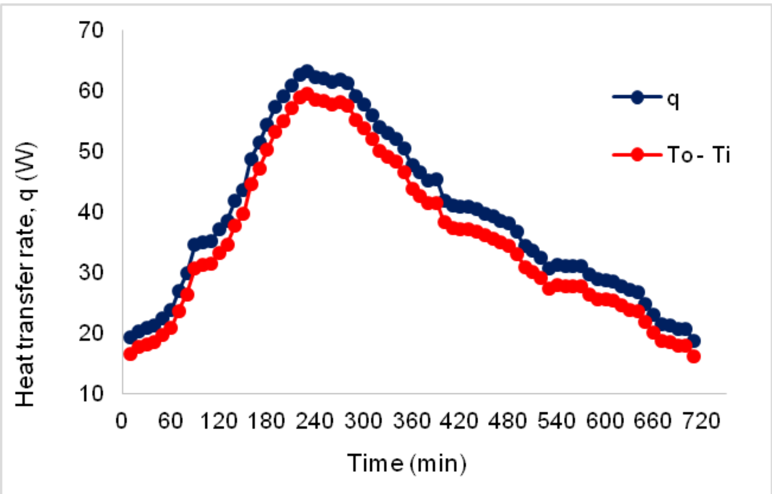

Fig. 7. Distribution of heat transfer rate (q) during the study period

Density (ρ) and dynamic viscosity (μ) are influenced by temperature and obtained from air tables based on film temperature (T_f) taken from Bergman et al. [8]. Density (ρ) and dynamic viscosity (μ) are directly proportional to temperature. The higher the temperature, the lower the density (ρ), and vice versa. The same thing also happened in a study conducted by Sahasrabudhe et al., that density decreased linearly with increasing temperature [17]. For dynamic viscosity (μ), a higher temperature is followed by increasing dynamic viscosity (μ) and vice versa. The average values of density (ρ) and dynamic viscosity (μ) are 1.0850 kg/m^3 with a range of 1.0398-1.1317 kg/m^3 and 195.43x10^{-7} N.s/m^2 with a range of (188.81-201.85)x10^{-7} N.s/m^2. This value is used to calculate the air mass flow rate ($\dot{m}$) and the Reynolds number (Re) as shown in Fig. 5.

Air mass flow rate ($\dot{m}$) and Reynolds number are calculated based on equations 3 and 1 with constant surface area and air velocity. In this study, the mass flow rate changed following the density change due to the rice husk mass change that occurred in the furnace. The average mass flow rate is 0.001099 kg/s with a range of 0.001053-0.001146 kg/s. A higher mass flow rate is followed by an increase in the Reynolds number and a decrease in the mass flow rate resulting in a decrease in the Reynolds number. The average Reynolds number is 2822.75 with a range of 2616.77-3044.83. From Fig. 6 it can be shown that the higher the Reynolds number causes the heat transfer rate to decrease and vice versa.

The heat transfer rate (q) that can be produced from black steel pipe heat exchangers and rice husk energy sources is an average of 39.19 W with a range of 18.62-63.19 W. The highest heat transfer rate occurs when the Reynolds number is at its smallest. In the study, it was found that the heat transfer rate was highest when the temperature reached a maximum as shown in Fig. 7. This happens when the rice husks in the furnace have turned into charcoal. The decrease in the heat transfer rate is in line with the reduced mass of rice husks in the furnace due to the absence of an additional mass of rice husks in the tests carried out. The heat transfer rate distribution pattern follows the temperature distribution trend during the test time. The heat transfer rate is directly proportional to the drying rate. The drying rate is higher in direct proportion to the increase in drying temperature [18]. It was found that when rice husk was turned into charcoal it had an impact on a high heat transfer rate. High heat transfer rates are needed in the drying process of a product so that the time is shorter and optimal. In addition, rice husk biomass can be used as alternative energy because it is easy to obtain, especially in agricultural areas that grow rice. Biomass is used to meet the energy needs of rural communities in developing countries to reduce the use of firewood and improve economic status [19,20].

4. CONCLUSION

Utilization of rice husk biomass as energy gives satisfactory results. This is done through an energy conversion process using a heat exchanger consisting of black steel pipes. These pipes are arranged in parallel to one air passage. The ambient temperature can be increased by an average of 11.70%, namely from (T_i) 305.10 K and a range of 300.60-307.40 K to (T_o) 340.80 K with a range of 317.25-366.30 K. The heat transfer rate (q) that can be produced is an average of 39.19 W with a range of 18.62-63.19 W. The highest heat transfer rate occurs when the Reynolds number is at the smallest value. In the study, it was found that the heat transfer rate was highest when the temperature reached a maximum. The heat transfer rate resulting from the utilization of a black steel pipe heat exchanger with rice husk energy can be used as an alternative to small farmer-scale dryers. This is the development of post-harvest dryers that are sustainable and energy efficient. In addition, rice husk has added value, which was previously just waste that was thrown away and polluted the environment.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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