Comparison between simulations and experiment for heat transfer characteristics in the re-burning kiln heat exchanger

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Abstract. Waste heat from the combustion process that is left unused may cause pollution problems and adversely affect health. This waste heat should be recovered. In this research, the simulation and experimental data on heat transfer characteristics of the pipe coiled inside the re-burning kiln heat exchanger were studied. The main objective of this study was to compare heat transfer coefficients obtained from the simulation using water as the working fluid with those obtained experimentally from the re-burning kiln heat exchanger for the drying system. The re-burning kiln heat exchanger was of coil-pipe type with an outside diameter of 38 mm. The coiled pipe set up on the re-burning kiln heat exchanger was 80 cm in width and 173 cm in height. The flow rate of the cold water used as a working fluid was varied from 10 to 20 LPM, while the surface temperature of the coil pipe was varied from 200±20°C to 400±20°C, respectively. Thermal conductivity and outlet temperature of the water were also measured as a function of the internal temperature and water flow rate. The experimental results were validated against the simulation. The results showed that when the flow rate of water inlet decreased from 20 LPM to 10 LPM, the temperature of the water outlet was increased from 52.4 °C to 76.3 °C respectively. An increase in the temperature of the water outlet because of increased the re-burning kiln heat exchanger temperature and reduced the mass flow rate of supply water. The obtained simulated heat transfer coefficient in the re-burning kiln heat exchanger was in agreement with the experimental results.

1. Introduction
Biomass is a widely known renewable energy source because it is clean and has unlimited availability, which relies on the processing of biological materials. The majority of the biomass comes from agricultural wastes. Utilizing biomass energy can be done in different methods, such as gas production, fermentation, and direct combustion (the reaction of the flue combustion from raw materials with oxygen that converts chemical energy into heat energy) [1, 2]. At present, heat energy is the right choice of power for various applications because it can reduce the energy use from crude oil, and coals. It is the energy that is derived from uncomplicated production processes. Heat transfer characteristics are essential in a re-burning kiln heat exchanger. The waste heat is passed through the process of value addition by recovering [3-5]. Waste heat that is released from industrial incinerators or even biochar processes can be further utilized to create the re-burning kiln. Products or the hot water from the experiment of the re-burning kiln can be extended to the drying industry. Rafal and
Tomasz [6] studied the effect of external coil surface modification on heat exchanger effectiveness. They also experimented with both laminar and turbulent flows. The results of the study indicated that the overall heat transfer coefficient increased with an increase in the inner coiled tube Dean number for a constant flow rate. Raei et al. [7] investigated the heat transfer coefficient and friction factor of water-based $\gamma$-Al$_2$O$_3$ nanofluid in a double tube with flow rates in the range of 7–9 l/min. They showed that the ratio of the overall heat transfer coefficient of nanofluid to that of pure water decreased with increasing nanofluid flow rate. Majid et al. [8] studied the heat transfer coefficient of pure water and nanofluid flowed inside a horizontal double-tube under turbulent flow. The results of this study indicated that the heat transfer coefficient of nanofluid was higher than that of base fluid with a maximum thermal performance factor of this nanofluid of 1.266. Ramin et al. [9] investigated the effect of using water/graphene oxide nanofluid as a working fluid on heat transfer and pressure drop. They reported that the heat transfer performance coefficient was increased by up to 42.2%, indicating enhanced heat transfer compared to undesirable pressure drops in the test. Bahmani et al. [10] studied the heat transfer and turbulent flow of water/alumina nanofluid in a parallel as well as the counter-flow double pipe heat exchanger. Results of this study indicated that increasing the nanoparticles volume fraction or Reynolds number led to an enhancement of Nusselt number and convection heat transfer coefficient. The maximum rate of the average Nusselt number and thermal efficiency enhancement was 32.7% and 30%, respectively. Kumar et al. [11] studied a tube-in-tube helically coiled heat exchanger for a turbulent flow regime. The numerical investigations were done to understand forced laminar fluid flow in rectangular coiled pipes. Conte and Peng [12] addressed on exploring the flow pattern and temperature distribution through the pipe. In this study, the temperature inside the re-burning kiln [13-14] was measured and compared against the simulation results from the re-burning kiln via solving simplified equations of heat transfer, such as the conduction, the convection, and the radiation [15]. The objective of this study was to compare heat transfer coefficients obtained from the simulation [16-19] used to evaluate the dissimilarity of the parameters that affected the temperature of the water outlet.

2. Materials and Method

2.1. Re-burning kiln detail
The Re-burning kiln was made of carbon steel with a height of 173 cm, the inner diameter with a width of 80 cm, and a thickness of 2 mm. The bottom of the re-burning kiln has an air intake channel of 40 cm x 15 cm (width x height), and it was able to refill the fuel by a fuel intake channel 30 cm x 30 cm (width x height). The inside of the re-burning kiln has a coiled pipe with internal water to exchange heat from the furnace. The pipe coil was made of stainless steel with a diameter of 3.8 cm, which is shown in figure 1.

Figure 1. The dimension of the re-burning kilns.
2.2. Experimental setup
The efficiency of the re-burning kiln depended on essential parameters such as water flow rate, the amount of fuel and the fuel must have moisture content lower than 10 % w.b. The thermocouples were installed at various points in the re-burning kiln to measure the temperature changes. The testing process took approximately three hours. First, the water flow rate was set between 10-20 LPM. The fuel was loaded into the re-burning kiln. Then, ignition and combustion were established. The re-burning kiln was designed to be able to refill from the side. Eight K-type thermocouple probes were set up at eight positions in the re-burning kiln heat exchanger setup, shown in Figure 2. The number 1 to 8 show: (1) the water that output from the re-burning kiln, (2) the water inlet to the re-burning kiln, (3) the water outlet from the fan, (4) the water inlet to the fan, (5) the air inlet to the fan, (6) the air outlet from the fan, (7) the water storage tank and (8) the top of the re-burning kiln. The temperatures were logged in real-time and stored in the computer using a Wisco Online Data logger OD04. When the test was over, the hot water could be used to calculated the efficiency and compared the actual test and the computer simulation.

![Figure 2. The experimental setup.](image)

2.3. Experimental Procedure
The simulation of heat exchange through a coiled pipe inside a re-burning kiln with different water flow rates was conducted using a computer program. Initially, the material type for the oven and coiled tube was determined. The temperature and the airflow rate within the furnace were assumed to be constant. The temperature of the inlet and the outlet water of the re-burning kiln and the time used in the test were. The simulation results will be compared with the experimental results to verify the accuracy of the model.

3. Results and Discussion
3.1. The comparison of water outlet temperature of simulation results with the experimental results
The simulation results were compared against the experimental data, with a focus on the temperature of the outlet water from the re-burning kiln throughout the experimental procedure within 180 min at different flow rates (i.e., 10 LPM, 15 LPM, and 20 LPM). The augmentation of temperature at a different time, as shown in figure 3. The highest temperatures from simulation and the testing, as shown in table 1. The results were in a similar pattern with the research of Jing Du et al. [20] were found was the heat transfer rate of the heat recovery exchanger with coiled pipe mainly depends on the values of the heat transfer area of the coiled pipe. Including the time was running on the process.
Table 1. Comparison of water outlet temperature distribution between simulation and experimental results.

| Water flow rate (LPM) | Experimental results (°C) | Simulation results (°C) |
|-----------------------|---------------------------|------------------------|
| 10                    | 76.3                      | 81                     |
| 15                    | 64.1                      | 66                     |
| 20                    | 52.4                      | 55                     |

Figure 3. The temperature of the water outlet as a function of the water flow rate.

3.2. The effect of water flow rate on water outlet temperature

The impact of the water flow rate, it can be seen from the experimental data that, when the number of flow rate increases, water outlet temperature decreases, between the hot air inside the re-burning kiln that flowed through the coiled pipe and the water flow rate inside the coiled pipe, as shown in figure 4.

Figure 4. The effect of water flow rate on the temperature of water outlet.
The results of heat exchange from this study as shown in figure 4. It was generally known, when the water flow rate changed, it greatly affected the water outlet temperature. At the water flow rate of 10 LPM, the maximum water outlet temperature was 76.3±1.2 °C. The temperature dropped to 64.1±1.8 °C and 52.4±1.3 °C when the water flow rates were set to 15 and 20 LPM, respectively. It can be concluded that the temperature of the outlet water from the re-burning kiln inversely varied with the water flow rate inside the coiled pipe. From the comparison with the water outlet temperature obtained from the simulation, it was found that the results were in a similar pattern. Which corresponds to the research of Yin et al., [21] studied the tube-side heat transfer coefficient and water outlet temperature with different mass flow rate. Found that the water outlet temperature has the highest temperature at the flow rate of 0.25 LPM and will decrease continuously when the water flow rate increases to the final value of the test are 2.50 LPM. It was found that the results were in a similar pattern.

3.3. Effect of the temperature inside re-burning kiln on water outlet at 10 LPM

![Figure 5. The effect of the temperature inside the re-burning kiln on the water outlet temperature at 10 LPM.](image)

It was found that the water flow rate of 10 LPM showed the best result compared to other flow rates (15 LPM and 20 LPM). When the temperature inside the re-burning kiln increases, the water outlet temperature increase too. The chart illustrates the rise in water outlet temperature on the temperature inside the re-burning kiln increased from 200±20 °C, to 400±20 °C. When the re-burning kiln temperature increase from 200±20 °C to 300±20 °C and 400±20 °C, the water outlet temperature was increased from 38.0±1.05 °C to 48.6±3.3 °C and 76.3±1.2 °C, respectively. The reason that made the temperature inside the kiln changed was the time needed to make the ignited point, as shown in figure 5.

3.4. Temperature distributions

The temperature distributions of the water flow inside the different spirals were simulated for the variations of temperature in the re-burning kiln, as shown in figure 6-8. When the temperature was about 300 °C or more, good heat exchange between the water inside the coiled pipe was expected. This corresponds to the research of Panyoyai et al.,[13] for the slow pyrolysis, the biomass is heated under the low to moderate temperature ranging from 300 °C to 500 °C for an extended period varying between 30 min to 3 hours. The temperatures profile inside the re-burning kiln were shown in figure 6-8. It was found that when the water flows rates increase the temperature inside the coiled pipe decrease. The hot water obtained can be used for the drying system, which requires further study of the size, length, and working fluid inside the coiled pipe. Including installing heat exchanger fans for the drying system.
Figure 6. Temperature distribution in the re-burning kiln with water flow rate at 10 LPM.

Figure 7. Temperature distribution in the re-burning kiln with water flow rate at 15 LPM.

Figure 8. Temperature distribution in the re-burning kiln with water flow rate at 20 LPM.

4. Conclusion
- The water flow rate at 10 LPM showed the best result for the temperature of the water outlet from the re-burning kiln. When the water flow rate was increased, the temperature of the water outlet was decreased.
- The most important effect of heat transfer in this study is the changed in temperature. If the temperature inside the re-burning kiln has a suitable temperature of 300 °C and stable cause heat exchange efficiently.
- The result from the experiment and the simulation were compatible with quantitatively and qualitatively.

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