Simulation and experimental analysis of shell and tube heat exchanger for the drying system

Songchai Pankaew¹, Samerkhwan Tantikul¹, Thanasit Wongsiriamnuay¹, Tipapon Khamdaeng¹, Nakorn Tippayawong² and Numpon Panyoyai¹*

¹Faculty of Engineering and Agro-Industry, Maejo University, San Sai, Chiang Mai, 50290, Thailand
²Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai 50200, Thailand
*E-mail: n.panyoyai@gmail.com

Abstract. In this research, heat transfer simulation is a part of the application of heat transfer from the biochar production process for the drying system. This research aimed to investigate the three-dimensional transient conditions of the simulation used to predict heat transfer of heat exchangers comparing with the experimental study. The working fluid used inside the tube was hot water with a mass flow rate of 10 LPM. The results obtained from the simulation and the experiment analysis were heat transfer from hot water to cold air through the heat exchangers. The temperatures of hot water inlet the heat exchanger were set as 50, 60, 70, and 80 °C, respectively. Air flowed through the heat exchangers was set as 1 m/s, 2 m/s, 3 m/s, 4 m/s, and 5 m/s, respectively. The coil pipe has the outsider diameter at 1.9 cm and four panels. It was set up on a box case with 100 cm of width and height and 45 cm of length. The results showed that when the water temperature increased from 50 °C to 80 °C and airflow speed through the heat exchangers of 3 m/s, the temperature difference of air through the heat exchangers increased from 3.2 °C, 4.7 °C, 5.20 °C and 6.2 °C respectively. On the other hand, when the airflow speed through the heat exchangers increased from 1 m/s to 2 m/s, 3 m/s, 4 m/s and 5 m/s respectively, the temperature difference of air through the heat exchangers decreased from 11.81 °C to 7.33 °C, 6.20 °C, 5.20 °C, and 5.05 °C respectively. The simulated heat transfer coefficient inside the region of heat exchangers was an agreement with the experimental data. The results indicated that the simulation could be attained in the system compared with the actual experimental analysis.

1. Introduction

Waste heat is generated in a process by way of fuel combustion or chemical reaction and dumped into the environment even though it can still be reused for some useful and economic purpose due to limited resources and environmental problems. If waste heat can be recovered, an amount of primary fuel can be saved. The energy is recovered from exhaust gas can be stored in the form of sensible heat. However, the amount of heat can be recovered and lost slightly by using the drying system [1]. Energy efficiency and energy recovery should be insured to avoid unnecessary entropy production, but also to make processes more effective, environmental and friendly [2]. The performance of an exhaust heat recovery system has optimized the design of heat exchangers. Working with fluid pressure and
orientation in the heat exchangers was also optimized [3]. The heat exchanger models and simulation had been used extensively due to their importance in industrial applications. Many kinds of heat exchanger models had been developed for different targets. The heat exchangers were the test for the thermal energy system aiming to study the drying system [4]. The design of heat exchangers in the drying system had several aspects, such as the phase of the working fluid, the material selection, the type of construction, or the optimization of geometrical parameters that had to be taken into account. The components of optimization in the drying system were based on reliable models and methods. The appropriate design and dimensioning of the heat exchangers were accurate to the prediction of heat transfer coefficients (HTCs) [5]. The heat exchangers are widely used for efficient heat transfer from one medium to another. Nanofluid is a potential coolant that can provide excellent thermal performance in the heat exchangers [6]. Many authors investigated the heat transfer experimentally in the shell and tube heat exchanger. [7-10] Heat transfer augmentation was more sensitive to increase temperature comparing with to increase mass flow rate [11]. The effect of fluid inside the internal circulation system of shell and tube heat exchangers was complex because of the influence of many factors. The flow distribution had a significant influence on the performance of fluidic apparatus such as the shell and tube heat exchangers. The non-uniformity of flow distribution reduced the efficiency of the process. The result of tube arrangement on the flow distribution was presented by CFD simulation. The obtained results showed that the arrangement of tubes had a significant influence on the flow distribution [12]. The study of the flow distribution of the second tube-pass with conventional header configuration was uniform enough to use in practice [13]. The thermal performance factor reduced by increasing of hot water flow rate. The thermal performance factor of wave tubes was found being larger than smooth tubes. Optimizing of the procedure indicated the thermal performance factor, the lower values of a wave starting length, hot water flow rate, higher values of cold water flow rate and a wavelength, and heat transfer rate in a shell and coiled tubes heat exchangers experimentally [14], S.M. Peyghambarzadeh et al. [15] found that when the liquid flow rate was changed in the range of 2 – 6 LPM and the fluid inlet temperature has been changed for all the experiments. The results demonstrate that the flow rate clearly enhances heat transfer compared. Sukkarin Chingulpitak et al. [16, 17] studied a comparison of the refrigerant flow characteristics in heat exchanger and hot water flowed in the helical tube and cold water flowed in the shell side. The higher coil diameter, coil pitch, and mass flow rate in the shell and tube heat exchangers could enhance the heat transfer rate in these types of heat exchangers. [18] Many authors investigated simulation the heat transfer in shell and tube heat exchanger. [19, 20] This paper presents the simulation results from the heat exchanger models against the experimental data at design condition, steady-state and transient prediction. This work focused on the comparison and evaluation of the shell and tube heat exchanger models and the purpose of the process in the simulation and the control design. The simulation results from the models had been compared against experimental data from the shell and tube heat exchangers. The heat exchangers were tested for the thermal energy system and the study of the drying system.

2. Materials and methods
The characteristics of the coil heat exchangers used in this experiment shown in Figure 1 and Table 1 respectively. The temperatures of hot water inlet the heat exchanger were set as 50, 60, 70 and 80 °C, respectively. A mass flow rate of hot water was set at 10 LPM. The airflow rate were set as 1 m/s, 2 m/s, 3 m/s, 4 m/s and 5 m/s respectively. 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 air temperature difference could be used to calculate the efficiency of the heat exchanger in this study and compared it with the simulation.
Table 1. Properties of heat exchanger equipment.

| Element                  | Style |
|--------------------------|-------|
| Coil heat exchangers     | 4     |
| Length of heat transfer  | 80 cm |
| Pipe coil thickness      | 1.65 mm |
| Pipe coil diameter       | 1.9 cm |
| Box height               | 100 cm |
| Box width                | 100 cm |

Figure 1. The model of heat exchanger.

Figure 2 shows the experiment set up in this study. The testing process took approximately 3 h. First, the water flow rate was set as 10 LPM. The fuel was loaded into the re-burning kiln. Then, ignition and combustion were established. Six K-type thermocouple probes were set up at 6 positions in the heat exchanger setup, shown in figure 2. The number 1 to 6 show; (1) the water that inlet to heat exchanger,
(2) the water outlet to the re-burning kiln, (3) the air inlet to the heat exchanger, (4) the air outlet to the drying dome, (5) the water in the tank and (6) the ambient air.

3. Results and discussions

3.1 Simulation results of water flow in coil pipe and airflow through the heat exchangers

The results of the simulation on heat exchangers were shown in figure 3. Mass flow rates of hot water were set at 10 LPM. Hot water inlet temperature was set as 60 °C, 70 °C and 80 °C, respectively and airflow was controlled at 3 m/s. The flow visualizations illustrate that the airflow outlet increases as the water temperature flow passed through coil tubes increase. The increased temperature of the water inlet helps to improve the rate of heat transfer in the heat exchanger. Flow patterns in the coil tube zone observed were compared with the experimental result. It was found that the simulation was a similarity with the innovation.

a. hot water at 60 °C

b. hot water at 70 °C
3.2 The effect of airflow on the air temperature difference.

Table 2. The air temperature difference on the heat exchanger (water temperature = 80 °C).

| Airflow (m/s) | Water inlet (°C) | Water outlet (°C) | Air inlet (°C) | Air outlet (°C) | Temperature difference (°C) |
|--------------|------------------|-------------------|---------------|----------------|-----------------------------|
| 1            | 82.64            | 77.44             | 34.00         | 22.50          | 11.81                       |
| 2            | 77.94            | 71.10             | 30.98         | 23.65          | 7.33                        |
| 3            | 77.44            | 66.97             | 32.71         | 26.51          | 6.20                        |
| 4            | 76.13            | 67.52             | 31.06         | 25.87          | 5.20                        |
| 5            | 77.40            | 68.35             | 31.58         | 26.54          | 5.05                        |

Figure 4. Effects of airflow inlet on temperature difference (hot water at 80 °C).

Figure 4. shows the effects of airflow inlet on air temperature difference, while hot water was controlled at 80 °C. The results of air temperature difference at airflow of 1, 2, 3, 4 and 5 m/s were
11.81, 7.33, 6.20, 5.20 and 5.05 °C respectively. It was found that when the airflow inlet increased, the air temperature difference on the heat exchanger was decreased.

3.3 The effects of water inlet temperature on the air temperature difference.

Table 3. The air temperature difference on heat exchanger, airflow 3 m/s.

| Hot water (°C) | Water inlet (°C) | Water outlet (°C) | Air inlet (°C) | Air outlet (°C) | Temperature difference (°C) |
|---------------|------------------|-------------------|----------------|-----------------|-----------------------------|
| 50            | 53.38            | 49.71             | 30.71          | 27.60           | 3.2                         |
| 60            | 56.38            | 51.0              | 29.92          | 25.22           | 4.7                         |
| 70            | 70.57            | 64.77             | 31.70          | 26.48           | 5.2                         |
| 80            | 77.44            | 66.97             | 32.71          | 26.51           | 6.2                         |

Figure 5. Effects of water inlet temperature on air temperature difference (airflow at 3 m/s).

Figure 5. shows the effects of water inlet temperature on air temperature difference, airflow 3 m/s. The results of air temperature difference at hot water of 50, 60, 70 and 80 °C were 3.2, 4.7, 5.2 and 6.2 °C respectively. The result shows that, when the water inlet temperature through the heat exchanger increased, the air temperature difference on the heat exchanger was increased.

4. Conclusions

In this research, it can be concluded that simulation results had been compared against the experimental data in terms of accuracy and simulation time. The results indicated that the simulation could be attained to the system compared with the actual experimental analysis. The following paragraphs summarized the main conclusions drawn from the study.

- Effect of airflow on the air temperature difference, it was found that when the airflow increased, the air temperature difference on the heat exchanger was decreased.
- Effects of water inlet temperature on the air temperature difference. When the water inlet temperature through the heat exchanger increased, the air temperature difference on the heat exchanger was increased.
- The results indicated that the simulation could be attained in the system compared with the actual experimental analysis. The simulated heat transfer coefficient inside the region of heat exchangers was an agreement with the experimental data.
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