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Biomass Burner with Flue Gas to Air Heat Exchanger for Rubber Sheet Drying

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ABSTRACT: Drying is one of means for preservation of many kinds of agricultural products, food and rubber. The aim of this paper is to design and construct biomass-fueled dryer which its operation subject to forced convection to dry the rubber sheets. The multi-pass shell and tube heat exchanger was fabricated and installed inside a small biomass oven to produce hot air and supply to the drying chamber. This dryer is designed for small-scale commercial producers of agricultural products in non-electrified locations. Several stainless steel tubes and junction boxes were connected to build the air flow path through the heat exchanger. A 370W centrifugal blower was employed to force the air to flow throughout the piping system. A return air duct was constructed for efficient use of combustion energy. To effectively run the system, the preheating period should be set in the first hour by providing 5 kg firewood at the beginning. Next, the rubber sheets were loaded into the drying chamber and the firewood feed rate was 1 kg per hour. During 4 hours of drying, the system was able to keep the temperature in drying room at $54.3 \pm 3.5\,^{o}C$ and the total weight loss of a sample rubber sheet was 90 gram.

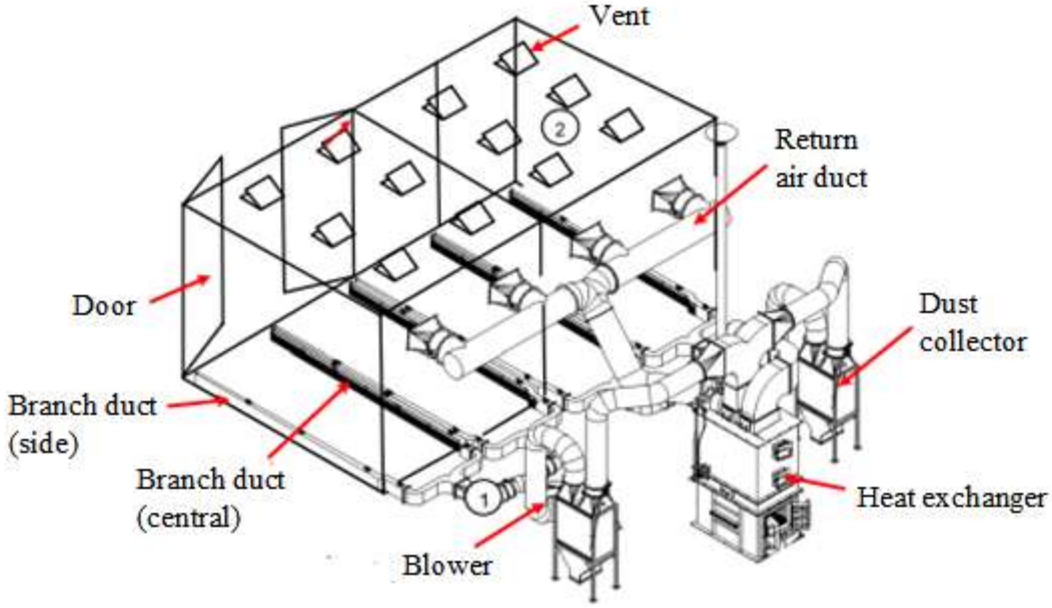
KEYWORDS: Dryer, Air heating, heat transfer, rubber sheet

INTRODUCTION

Thailand exported rubber products of 4.56 million tons representing 35.9% of world production in 2017 [1]. 76.8 percent of Thai rubber was concentrated latex and Ribbed Smoke Sheet (RSS), block rubber and compound rubber. RSS accounts for 12.9% of all products [1].

Drying process is an important step in producing RSS and block rubber. The conventional method of rubber drying in Thailand was the smoke tunnel system. The hot smoke is the flue gas from firewood combustion was directly supplied to the drying room via the small holes on the floor. The disadvantages of this system were high fuel consumption, time consuming, high heat loss and high risk to catch fire.

In the past, most researchers used the heat exchanger to supply the hot air to drying room instead of the flue gas in conventional method to save the rubber sheet from fire. The research directions may be divided into two main ways. Firstly, the research interest was at the flow and temperature distributions inside the drying room [5, 6]. The effect of parameters to the hot air distribution in drying room was studied by the computational fluid dynamics tool and confirmed the drying performance by the experimental results. Secondly, the research interest was at the improvement of heat transfer from biomass source by using multi-pass gas-to-gas heat exchanger [2, 3], the waste heat recovery method was concerned and only the experimental results were reported. Figure 1 and 2 illustrate the overview of drying systems and flow arrangement of air and flue gas inside the heat exchangers of [2] and [3], respectively. Additionally, an alternative way of research direction in agricultural products drying focused on the simultaneously generation of hot air from both biomass combustion and solar energy that irradiated on the flat plate collector [4].



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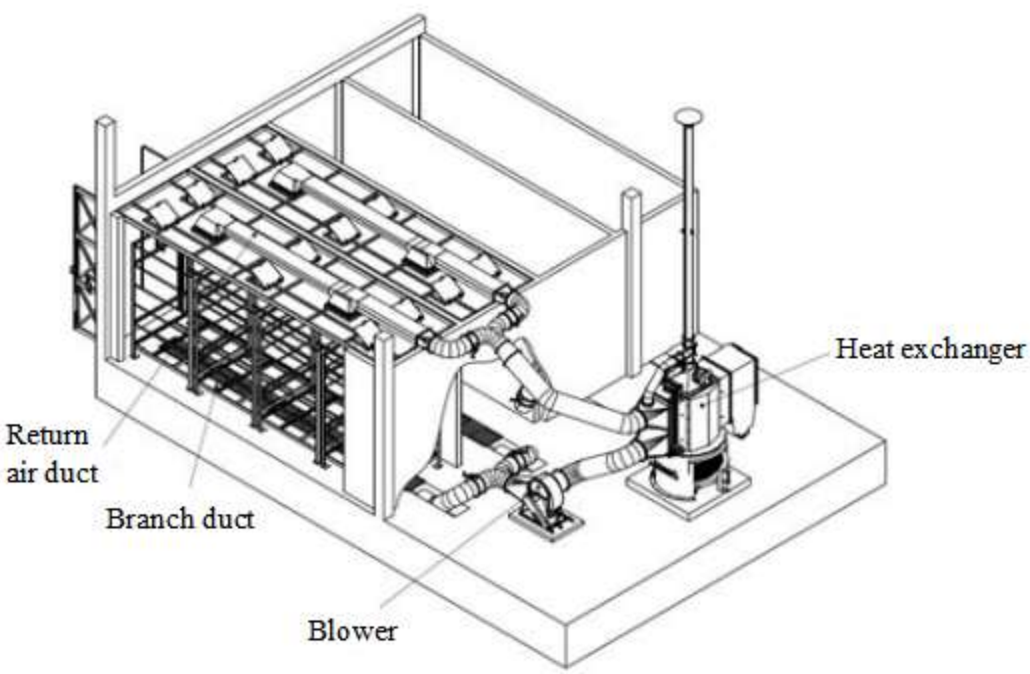
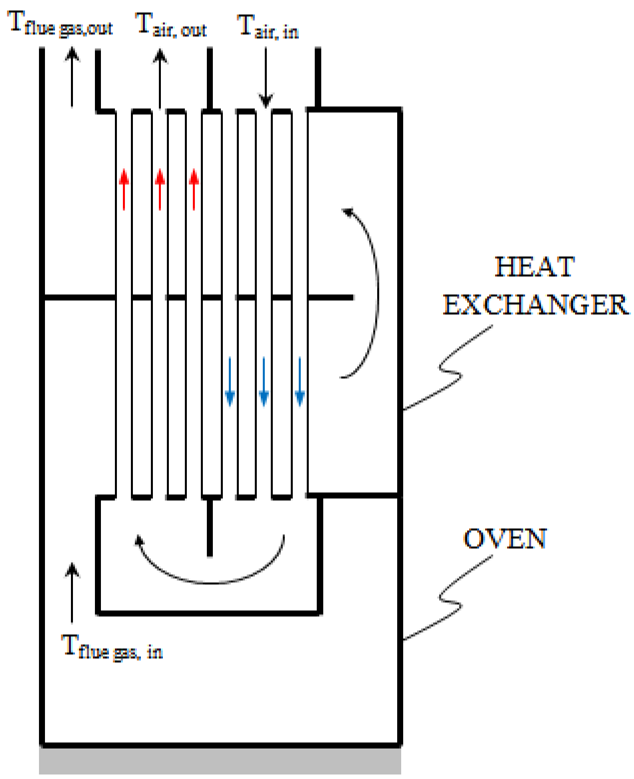


Figure 1. View of rubber drying system in literatures: (A) Medhiyanont et al. [2] and (B) Wongchang et al. [3]



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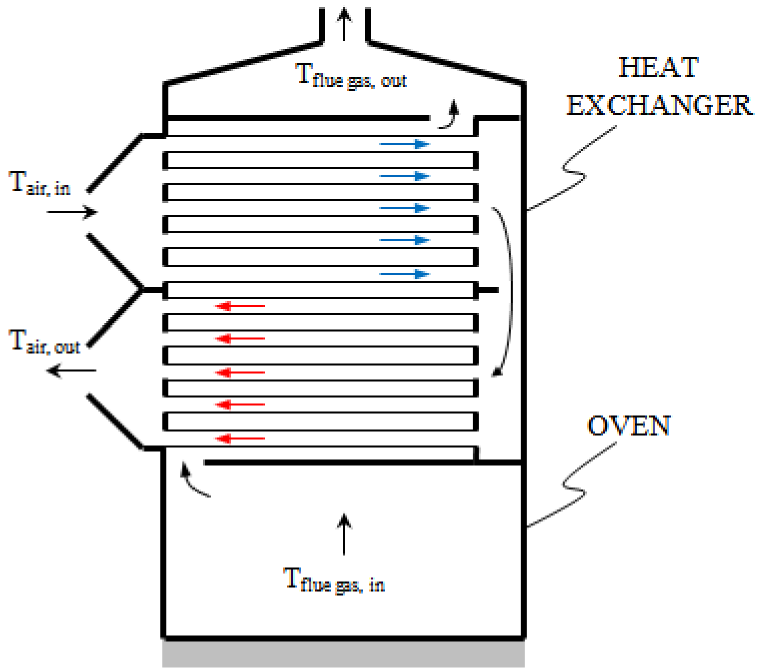

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Figure 2. Previous heat exchanger designs in rubber drying system: (A) Medhiyanont et al. [2] (Vertical tube) and (B) Wongchang et al. [3] (Horizontal tube)

The objectives of previous systems [2, 3, 5, 6] were to reduce the fuel consumption and drying time in rubber sheet drying. This paper concerns about these goals also. Therefore, the aims of the present study are to present the thermal performance of new gas-to-gas heat exchanger installed in biomass oven under different firewood feeding strategies according to reduce the fuel consumption and maintain the proper drying temperature for rubber sheet. In the preliminary experiments, the drying system was worked without rubber sheets to find the best fuel feeding conditions. Later, the rubber sheets were loaded into the drying room to investigate the weight loss of sample rubber sheet.

MATERIALS AND METHODS

Description of The Drying System

The current biomass-fueled drying system consists of 1) a biomass burner, 2) a blower, 3) pipes, and 4) drying chamber. The working procedure of system can be summarized as follows. The combustion between air and firewood in biomass burner gives heat energy to the whole system. The cold air enters the heat exchanger, takes the heat to raise its temperature and flow into the drying chamber. Next, the fluid flows through a distributor to achieve the requirement of uniform velocity distribution of hot air in drying chamber. Lastly, the total amount of hot air may be leaved the drying chamber when the moisture in the drying chamber is too high or partly returned and mixed with the fresh air and later flows to the heat changer when the moisture in the drying chamber is not too high.

Heat Exchanger

The size of present heat exchanger has dimension approximately of 0.80 m x 1.513 m x 1.05 m which smaller than the previous heat exchangers [2, 3] to accommodate with the small drying chamber (1 m x 1m x 1m) available in department of Mechanical Engineering. The low thermal conductivity of oven slab which is a composite of cement and brick, serves as an insulation of heat exchanger. The multi-pass heat exchanger was employed to increase the surface area of heat exchanger within the limited space. The junction boxes and circular tubes are welded together to be the channel of air flow along four surfaces of oven. The flue gas flows across the tube bundle and exits to chimney at the top of oven. The diagram of tube connection and installed heat exchanger are shown in Figure 4A and 4B, respectively. This present configuration of heat changer was different from the others [2, 3]. The flow diagram in figure 4A can be described as follows. Firstly, the cold air enters the heat exchanger from the left hand side. Next, air flows through two tube passes that parallel to the wall no. 1 from bottom to top. Secondly, air enters next junction box at the upper left of wall no.2 and flow through two tube passes that parallel to the wall no. 2 and 3 to the upper right of wall no.2. Thirdly, air enters the next junction box at the top of wall no. 4 and flows through the last two tube passes from top to bottom. Lastly, the hot air exits the heat exchanger at the bottom of wall no. 4. The total tube passes in heat exchanger is 6. The total number of tubes on side 1, 2, 3 and 4 are 80, 46, 46, and 80, respectively. The basic geometry of tube bank in each pass is called staggered. The computer aided design (CAD) model and actual pictures of drying chamber are shown in figure 5.

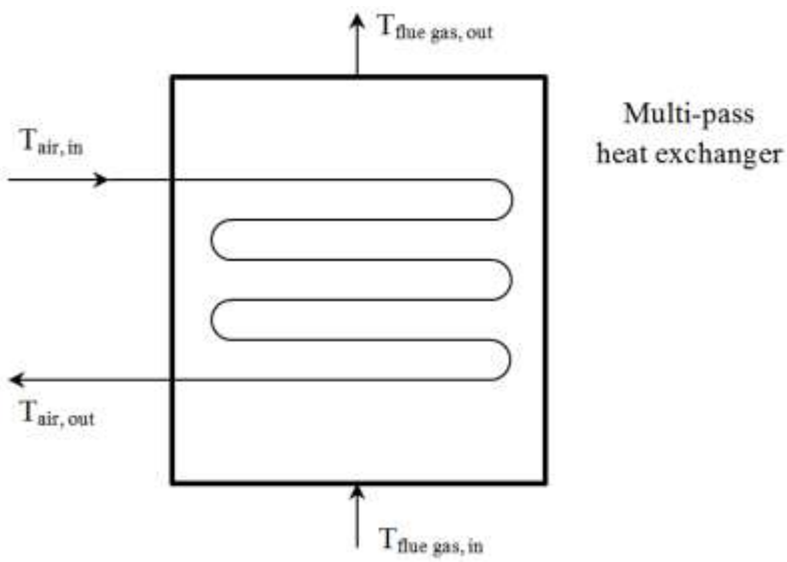

Figure 3. Simplified diagram of Shell and Tube heat exchanger in present system

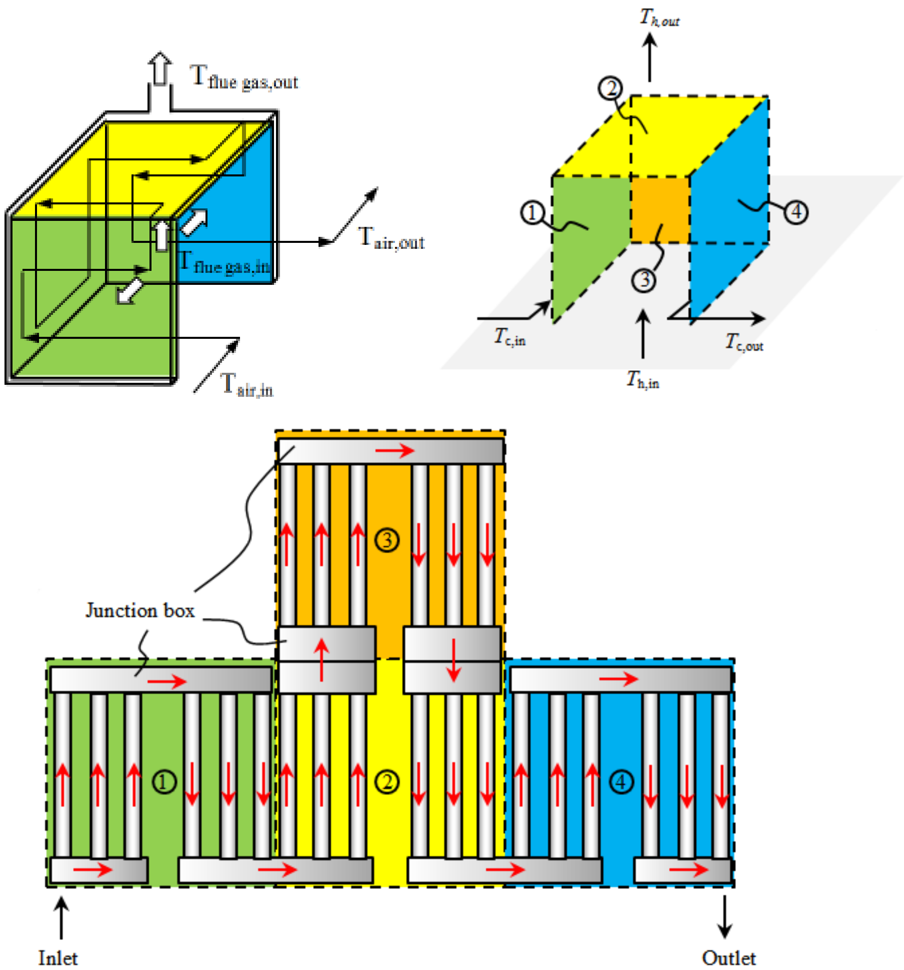

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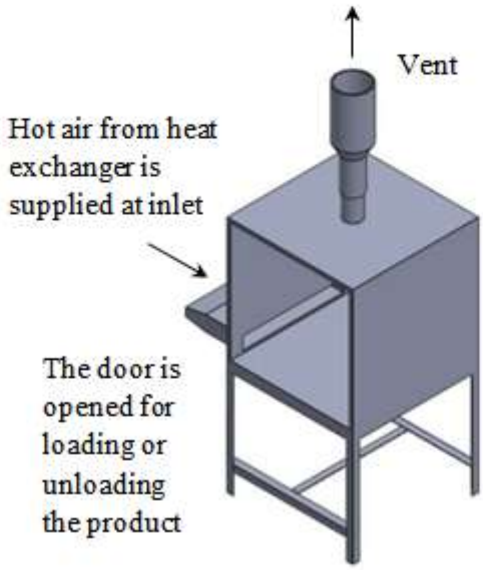
Figure 4. View of (A) Multi-pass of tube bundle with staggered tube arrangement of heat exchanger, (B) real heat exchanger.



A

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Figure 5. View of A) the CAD model of drying room, B) real drying chamber and hanging rails of rubber sheet

Rubber Sheet

In this study, the natural rubber sheets were purchased from a rubber market in Trung province, Thailand. The average dimension of rubber sheets was 50 cm x 90 cm x 0.4 cm. The initial average weight of rubber sheet was about 1.4 kg. The rubber sheet drying was conducted in the fifth test or the final test to keep the average temperature in drying chamber between 60 and 80 ^{o}C during the drying time. The total number of rubber sheets in the drying chamber was 20. A rubber sheet was sampled every one hour to evaluate the weight loss.

Instrumentation

Each ten minute of heating process, the temperature at various positions of drying system was recorded by data acquisition instrument connected to the thermocouple type K (0-600ºC), Micro sd-card 8 GB (memory card) and arduino MEGA 2560 R3 interfacing (micro-controller). The temperature at flue gas inlet was measured manually by infrared thermometer. The initial and final weights of rubber sheet were measured by digital weighting scale. The 16-points traverse method was employed to find the average air velocity and volume flow rate across the drying chamber. The instrument was a vane type anemometer. A 370 Watt centrifugal blower was employed to circulate the air in the whole system. The measured flow rate of hot air throughout the drying system was fixed at 35m^3/min.

RESULTS AND DISCUSSION

In this section, the experiments were carried out to find temperature variations at points along the drying system against time under different fuel feeding conditions. The results were used to assess the suitable fuel feeding condition for keeping the drying temperature within 60ºC and 80ºC. Also, the experimental results were employed to evaluate the suitable time to begin the rubber drying process. Table 1 shows five experiments that was done in this section. In the first test, 10 kg of firewood was fed only at the start of combustion to estimate the fuel consumption rate in oven, temperature at inlet and central of drying room. In the second and third tests, 5 kg per hour and 3 kg per hour were used, respectively, to evaluate the effect of constant fuel feed rates. Then, the linear decreasing fuel feeding rate was done in the fourth test. The second to fourth tests was done to find out the possibility to reduce the fuel consumption. In the last test, the feeding condition was changed to the staircase pattern in the fifth test. 5 kg of firewood was fed at the beginning of combustion to allow the oven to absorb the heat from fuel combustion called oven preheating. Then, the fuel feed rate was changed to 1 kg per hour in the next time period. The rubber sheets were loaded into the drying room after one hour of oven preheating. The performance in rubber drying was presented in the following subsection.

Table 1. The weight of firewood for combustion at each hour

Test No.	1st hour	2nd hour	3rd hour	4th hour	5th hour
1	10 kg	0 kg	Stop	Stop	Stop
2	5 kg	5 kg	5 kg	5 kg	Stop
3	3 kg	3 kg	3 kg	3 kg	Stop
4	5 kg	4 kg	3 kg	2 kg	Stop
5	5 kg	1 kg	1 kg	1 kg	1 kg

Figure 6 shows the change of temperature at outlet of heat exchanger and inlet of drying chamber in consistence manner. The temperature at outlet of heat exchanger is always higher than the temperature at inlet of drying chamber with the maximum difference 6.5 ^oC . The maximum temperature in drying room is 86 ^oC at 80 minute of combustion. This temperature was higher than the expected drying temperature. The temperature of drying chamber is 54.6 ^oC after 2 hours of combustion. This test ends at 2 hours because the fire is out. Thus, the feed rate of firewood should be at least 5 kg per hour in the first period of combustion in the next test.

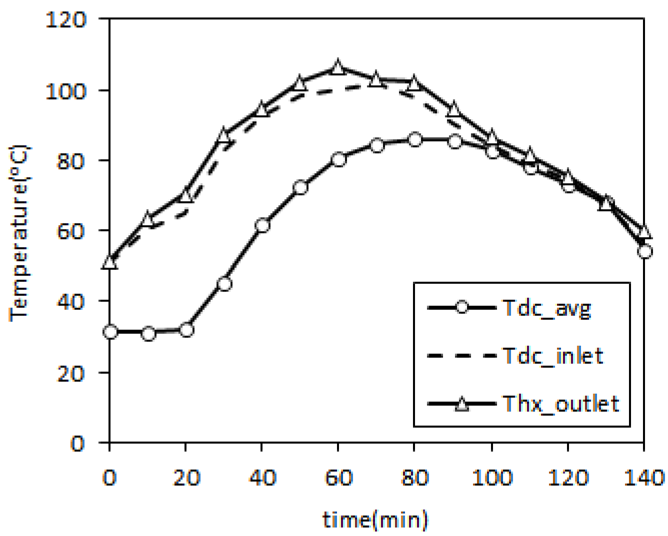

Figure 6. Temperature variations at outlet of heat exchanger, inlet of drying chamber and middle of drying chamber of the first test

In the second test, the uniform feed rate of firewood was fixed at 5 kg per hour. The combustion period was extended to four hours. The results of temperature variation with time at various positions were illustrated in Figure 7. The temperature in drying chamber is linearly increasing to 80 ^oC after 110 minute of combustion. The maximum temperature in drying chamber reached 109 ^oC when the combustion continued to 220 minute. This fuel feed rate was not acceptable because the amount of energy from firewood was too high. Thus, the fuel feed rate was lowered to 3 kg per hour in the third test. The results were shown in figure 8. The maximum temperature in drying chamber was 96 ^oC at 210 minute of combustion. The temperature variation in drying chamber can be controlled about $91 \pm 5.8\,^oC$ during the last 150 minute of combustion. However, this fuel feed rate did not satisfy the requirement of drying temperature. It should be noted that the temperature at two positions such as outlet of heat exchanger and inlet of drying chamber exhibited unexpected variation with time that may be the result of heat accumulation in the drying system. The fourth test concerned about the effect of the non-uniform fuel feed rate to the temperature in drying chamber. The linear descending scheme was employed for fuel feed rate.

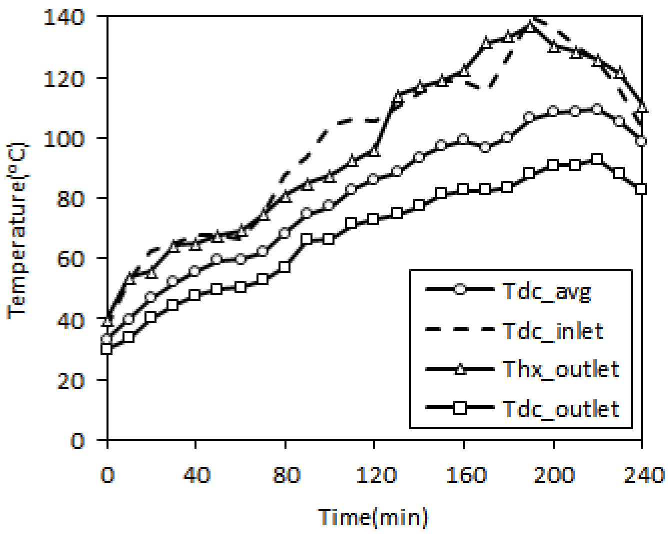

Figure 7. Temperature variations at outlet of heat exchanger, inlet of drying chamber, middle of drying chamber and outlet of drying chamber of the second test.

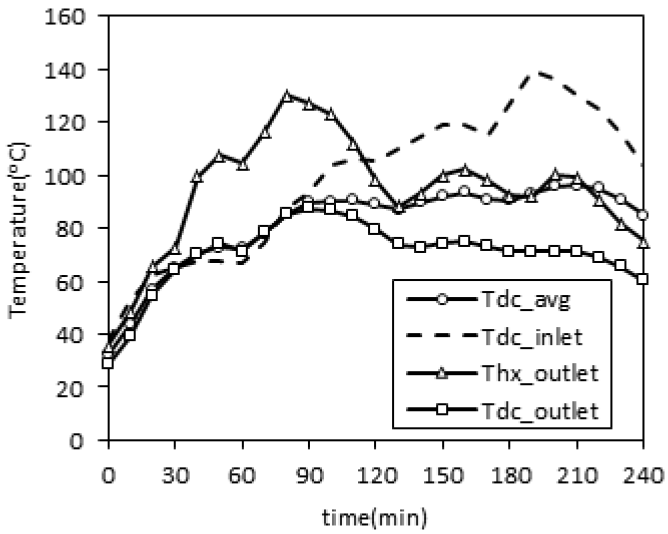

Figure 8. Temperature variations at outlet of heat exchanger, inlet of drying chamber, middle of drying chamber and outlet of drying chamber of the third test

Figure 9 shows the temperature variations along the flow path of air in the fourth test. In general, the maximum and minimum air temperatures were at the outlet of heat exchanger and the outlet of drying chamber. The temperature at the outlet of heat exchanger increased like a sinusoid wave with one hour interval while other temperature variations gradually increased. The average temperature in drying chamber during the last three hours was at $75 \pm 13.9\,^{o}C$. From this test, the fuel feed rate after the first hour should be decreased with other pattern to maintain the drying temperature in a small range. Thus, the fuel feed rate after the first hour was fixed at 1 kg per hour in the fifth test.

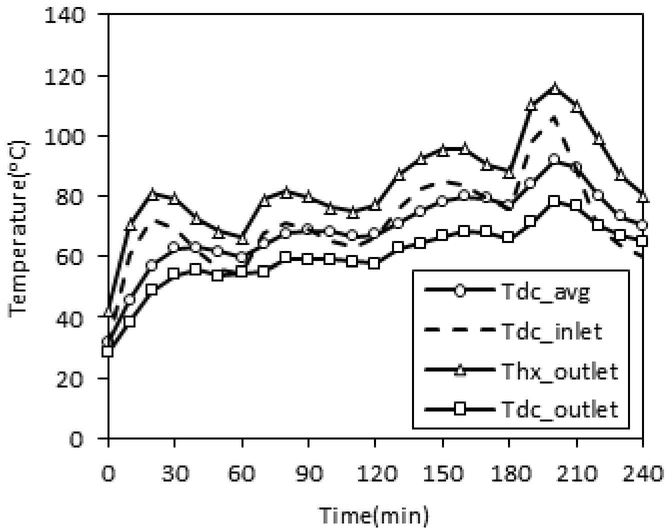

Figure 9. Temperature variations at outlet of heat exchanger, inlet of drying chamber, middle of drying chamber and outlet of drying chamber of the fourth test

Figure 10 shows the change of temperatures at various positions along the air flow path with time for the fifth test. The preheating period of system was in the first hour, the temperature at drying chamber was still higher than the expected temperature. It can be observed that the average temperature in drying chamber was at54.3 $\pm$ 3.5 ^{o}C during the last four hours. In conclusion, the fuel feed rate of the fifth test was the most satisfied fuel feed rate for drying rubber sheet. The rubber sheets were loaded in the system after the first one hour of combustion. The weight variation of a sampled rubber sheet during 4 hours of drying was plotted in figure 11. The total weight loss of a sampled rubber sheet was 90 grams.

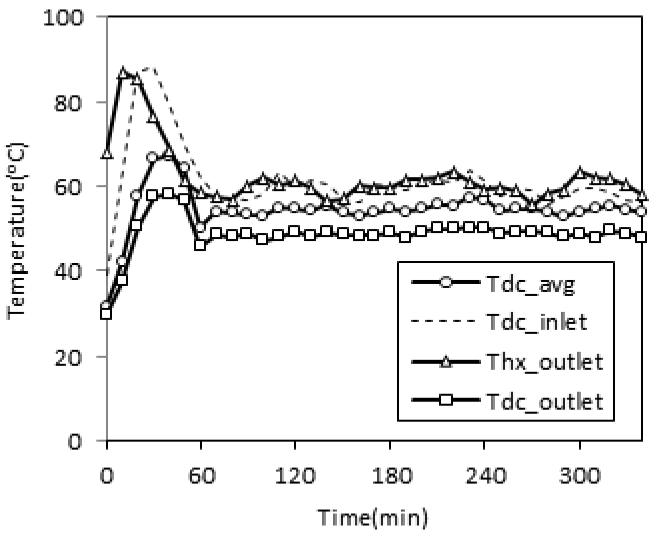

Figure 10. Temperature variations at outlet of heat exchanger, inlet of drying chamber, middle of drying chamber and outlet of drying chamber of the fifth test.

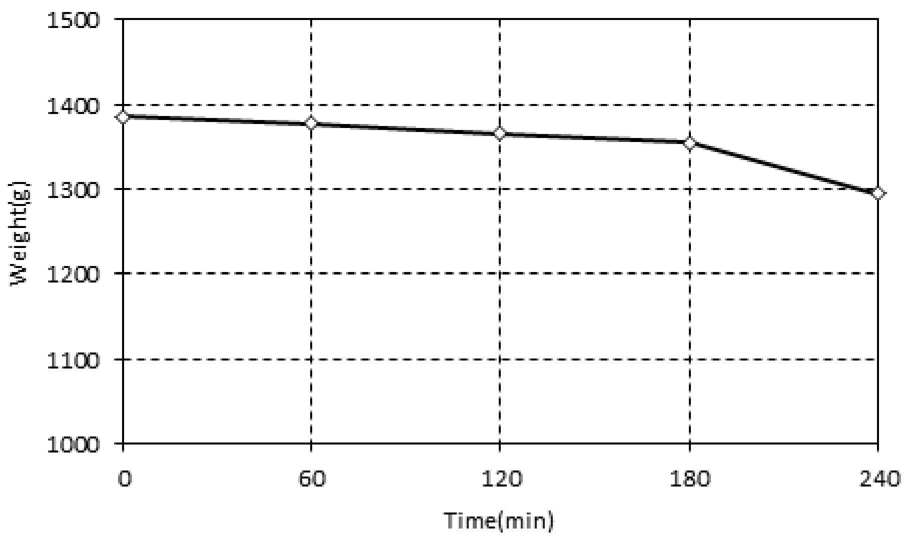

Figure 11 Changes in weight of a sampled rubber sheet during the drying process

CONCLUSION

A new multi-pass heat exchanger was designed, constructed and tested under five conditions of fuel feeding. It was installed in the rubber drying system. A fuel feeding condition in the fifth test was the best condition for rubber sheet drying in this forced convection dryer. The new design was able to maintain the temperature between 60 to 80^{o}C after 1 hour of oven preheating. The hot air inside the drying room was quite uniform with temperature deviation of 5^{o}C at the central part of drying room. The dryer was able to remove the water from a sample rubber sheet about 90 gram after 4 hours of drying. In the future, the drying period should be extended to at least about 3 days to monitor the moisture content in rubber sheet and compare with the experimental results from [2] in practical point of view. In addition, the dryer is too small to support 1000 kg of rubber sheets per batch so the extension of this design to the large drying room is an interesting topic. The fuel cost in drying operation should be reduced further by using the hot air from solar radiation in the daytime and the hot air from biomass fuel in the nighttime called backup biomass heater [4]. This dryer is able to apply to dry other agricultural crops and food products also and its performance in this drying topic has not been presented. Another next interest focuses to apply the advanced enhancement techniques such as twisted tape insert, etc., to multi-pass heat exchanger in biomass-fueled dryer.

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