The Industrial Waste Combustor Design for Hybrid Drying Ginger Production

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***Abstract*— A design of industrial waste combustor for the drying ginger production in Wangtong-polpuech industry, Phitsanulok, Thailand is presented. Hybrid of solar and biomass is used in the greenhouse solar tunnel dryer for drying gingers. The objective of the research is how to design the combustor for supplying heat to the dryer which the area of 8x20 m^2 and the time for drying is less than 30 hours. The shape of drying cabinet is parabolic that covered with polycarbonate for transmitting solar radiation of 1,872 MJ/day and the combustor is connected to the drying cabinet. The combustion of wood boxes, the industrial waste produces heat to exchange with the drying air flowing into the cabinet. Volume of the combustor is 4.50 m^3 for a highest fuel capacity rate of 97.33 kg/h, and produced heat of about 390 kW from the industrial waste with the efficiency of around 0.20. Ambient air is used to be the drying air for transfering heat from the combustor to the dryer and circulately return back to the combustor at a flow rate of 11.71 m^3/min. The sliced ginger of 1900 to 2200 kg are tested for drying from the moisture of 88% w.b to reach at 10% w.b in maximum time of 13.5 hours for determining the thermal efficiency, whereas the time of the solar drying is longer than the hybrid since the process cannot run in nigh time. In addition, the experiment for drying the highest batch of ginger mass production is set up with the ginger of 3,980 kg that valid to the calculation with the fuel error of about 10%.**

Keywords*—*Industrial Waste; Combustor; Hybrid Drying; Design.

I. INTRODUCTION

Agricultural product in Thailand is transformed to be a good product from more food industry by the simple process as drying. The most common drying method in this present is thermal drying which involves simultaneous heat and mass transfer [1]. In drying process, the most energy consumption in drying is electricity or heat from some kind of petroleum fuel that recently gets high cost and release greenhouse gas due to increase the global warming. Therefore the drying ginger system in the manufacture should reduce the pollution gas and investment cost by replacing the renewable energy to the electricity or petroleum fuel. The environmental friendly renewable energy sources are solar and biomass energy that select from the most suitable to the process of drying in the industry. Solar energy is free and clean energy resource for the drying process but there is the problem from the intermittent radiation due to frequent rain absorption and cloudy sky. When the solar energy is loss, the heat is supplied by the biomass fuel from fuel or some industrial waste. The industrial waste is wood box that is plentiful for taking as fuel. A combustor is designed to produce heat from burning the wood box waste and transferring heat to the air as drying fluid adding with the hot air from the solar collector to increase the drying temperature. A combustor design is started from the requirement of thermal drying energy and the drying time whereas the fuel is also calculated for supplying energy to the drying process and increasing the drying air temperature. Principle of combustion is used to calculate and determined the suitable combustor capacity and the drying chamber for producing products in each batch of the manufacture products [2]. Ginger is the plentiful agricultural product that available in Thailand and it also an ingredient of more instant food manufacture, some medicine and some beverage product. There is high income of the export from the large consumption in many countries that trading this product from Thailand. The purpose of this study is try to propose the renewable energy to the industrial sector that recently needs to use the clean energy in the process and remove the pollution for the ideal green manufactures.

Renewable energy from biomass and solar radiation are simply transformed to heat for drying ginger in the food industry and saving to replace to the electricity or heavy oil in the drying process. The heat from solar radiation is transformed by the collector on daytime but irregular due to cloudy day or rainy time, although most tropical regions experience of high solar radiation through the year, much of this radiation is absorbed by frequent rain and persistent cloud cover. A combination system of solar and biomass fuel is good agreement of the manufacture drying process for cleaning energy of green industry ideal. The proper biomass fuel for combustion is the waste from the wood box that left after transportation flesh ginger and reuse to be a biomass fuel. The combustor is designed for burning this waste for transferring heat to the air and flowing into the drying cabinet. Drying temperature is from 40°C to 60°C [3] and the higher temperature reduces the drying time that meets to the business competition from fast production and still preserve the quality product by using low cost and clean energy.

II. THE INDUSTRIAL DRYING GINGER PROCESS

A. The drying process

The industrial drying process starts by the workers slice ginger with the thick of 2-4 mm, record the weight and spread on the tray in the drying cabinet as shown in Fig.1 and heated the ginger in the drying cabinet until the moisture content decrease to the requirement moisture of the product. Moisture content is calculated by the relation to the weight of the ginger by sampling the sliced ginger and measure the weight and the moisture content every hour for determining the drying rate.

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The relation of the moisture content and the ginger mass as shown in equation (1) [4]

$$W_r = \frac{M_i - M_f}{(1 - M_f)} \quad (1)$$

Where M_i and M_f are initial and final moisture contents in fraction on a wet basis (w.b)

W_r is fraction of the ginger mass after water removed from by initial ginger mass.

Fig. 1 The sliced ginger spreads in the drying cabinet

The solar tunnel dryer is installed at Wangtong Polpuech, Phitsanulok, Thailand by the structure of iron frames in parabolic shape and covered with a transparent polycarbonate in the area of 160 m^2 for collecting the solar radiation. Drying air in the cabinet is warmed by the greenhouse effect and transfer heat to the ginger in 14 shelves of the tray stand vertically and the distance between columns is 1 m for working in the cabinet. For removing the hot humid air after drying the blower is installed at the front top of the cabinet for releasing the air at the rate of around 180 m^3/min and the new fresh air flowing in the cabinet to be drying air at the bottom channel of the dryer. The temperature and the radiation data of the dryer are collected for considering the drying results and design the combustor to reach the aim of the industry as shown in Fig. 2.

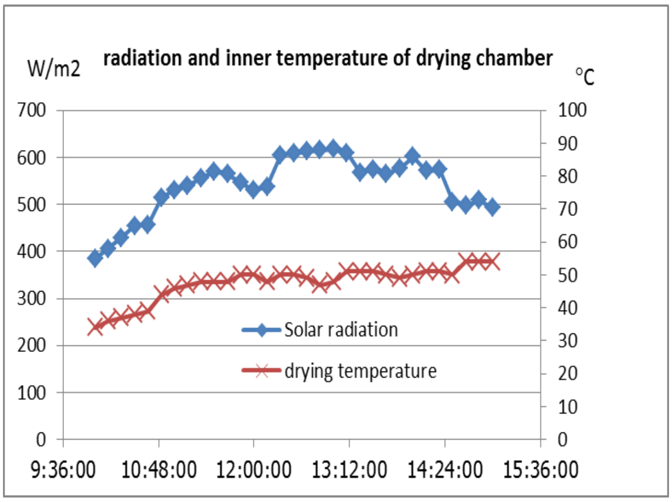

Fig. 2 Average data of radiation and temperature for a week

From Fig. 2, the average radiation is about 657 W/m^2 for 5 hours in one day and transform to heat warmed the air in the cabinet to reach the average temperature of 45°C with the energy of 1,872 MJ without loss. Drying time of solar drying for ginger mass of 2,200 kg is 7 days or 35 hours, therefore the efficiency of the dryer is 0.34. This data is shown the insufficient of drying energy by solar radiation therefore the combustor is used for increasing heat to the dryer to reach the higher temperature and reduce the drying time.

B. Heat from the bioass waste fuel combustion

The maximum batch product of the industry is around 4,000 kg, therefore the calculation of heat from the water evaporation is 8,318.22 MJ, and solar energy yields of 652.67 MJ for one day, therefore the energy deficit of 7,485.54 MJ is taken to produce by the combustor. A proper drying time of the industry for the good production business is around 1 day due to combustor works in nighttime for around 20 hours and on the day of low solar radiation, the combustor will produce maximum thermal rate by the highest fuel feed rate. The combustion fuel from the industrial waste is wood boxes that the industry collects for long after using in the order of thousand kg. Most of the wood box is biomass fuel which the lower heating value (LHV) of 15.80 MJ/kg due to the average wood moisture of 0.37 on a wet basis. Heat loss of the combustor is determined from the heating value of the fuel minus to the heat of the evaporation for removing the water of ginger in drying experiment. The combustion efficiency is calculated from the evaporation heat to the energy of fuel combustion and finding out the average value by varying the fuel mass and the ginger production as shown in the equation (2)

$$\eta_{th} = \frac{m_w h_{fg}}{m_{fuel} LHV} \quad (2)$$

Where η_{th} is thermal efficiency of the combustor

m_w is the mass of water evaporate from the ginger

h_{fg} is the enthalpy of evaporation

m_{fuel} is the mass of wood boxes

The average combustor efficiency is used to predict the fuel mass of each production batch and determined the fuel mass for preparing in the drying process, When the industry run the process at various ginger mass by the input material, the fuel feed rate is still constant for preserve the drying temperature but the drying time is different depend on the ginger mass.

The combustor is designed for the maximum batch of the ginger production and in the case of the lower batch production, the fuel feed rate is reduced to suitable with the heat of the water evaporate from that lower batch. The dimension of the combustor is 1x2x3 m^3 and made from the firebrick in the rectangular shape for the maximum fuel feed rate of 97.33 kg/h and the combustion air is calculated of 12.53 m^3/min with the excess air of 1.50 to reach a complete combustion. The pipe is connected between the dryer and the combustor by the diameter of 15 cm for the main pipe and separated to six small pipes to distribute the hot air to overall the drying cabinet. Drying air is driven by the electric pump installed at the front of the dryer and taken the air flow rate of 11.71 m^3/min circulated from the dryer to exchange heat with

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the combustor. The heat exchanger is installed at the top of the combustor with the exchange area of 10 m^2 for exchanging the burning air heat to the drying air. After the drying air heats, the hot air drives through the small six pipes from the bottom of the dryer to the ginger in the cabinet and then the moist air floats to the top and release out, while the preheated drying air in the cabinet is driven by the pump at the bottom of the dryer and flows into the main pipe to be drying air. The new drying air drives pass the combustor for transferring heat again and there is preheated before driving to the main pipe therefore the drying temperature is reached as the same in the cabinet instantaneously as shown in Fig. 3.

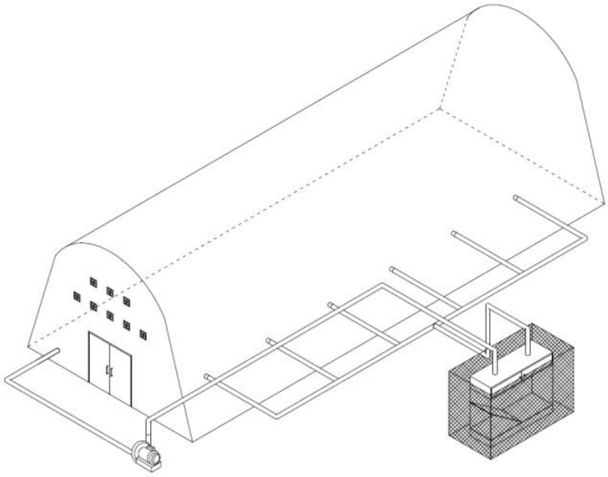

Fig. 3 Schematic diagram of the combustor connected to the drying chamber with the piping system

C. *Experiment for validating the design of the combustor*

Testing the combustor for finding out the efficiency to determine the fuel feed rate for each batch of the drying ginger is shown in the batch of 2,100 kg. The temperature is measured when the fuel feed rate testing average of 82.96 kg/h compared with the same average of solar radiation is shown in the Fig.4.

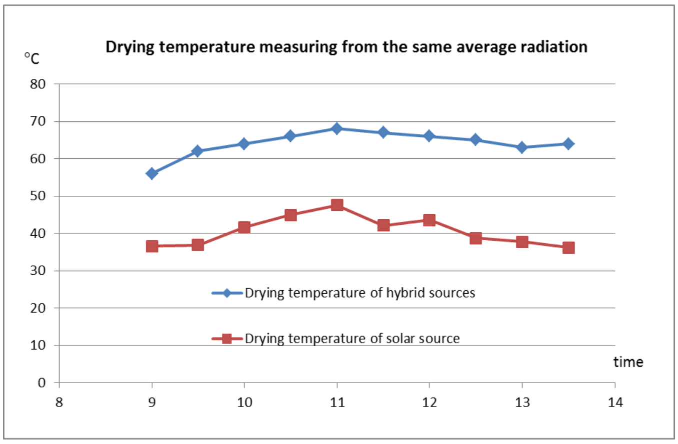

Fig. 4 The drying temperature of the two systems

From Fig. 4 the drying temperature is measured when the sun and the combustor produce heat together in the form of hybrid sources by the result as average of 63.92°C. The drying time is reduced to 13.50 h that reach the aim of the industry for competition of production time and saving cost including the clean energy by removing the waste and turn to be a biomass fuel as a renewable energy. The efficiency of the combustor is calculated of 0.20 from the ratio of the drying heat and the combustion heat and this result is valid with the calculation and the experiment with error of 0.1 as shown in the table 1. For the case of the maximum batch, the experiment is set up for measuring the fuel and the time by controlling the drying temperature at around 64°C by the same fuel feed rate of the other batch. The maximum ginger batch set up from the ginger of 3,980 kg and the fuel feed rate of 88 kg for expanding the drying time of 27 hours with the power of the combustor of 388.32 kW nearly to the other batches that corresponding to the calculation. The maximum fuel feed rate of the combustor produce power of 390 kW and the highest thermal lost is 30,258 MJ that calculates the combustor efficiency of 0.20.

TABLE I. HE EXPERIMENTAL RESULTS OF THE COMBUSTOR FUEL FOR VARIOUS GINGERS

Parameters	Sliced ginger (kg)				
	1900	2000	2100	2200	3980
Wood boxes fuel from calculation	1095.5	1166	1232	1292.5	2388.6
Wood boxes fuel from experiment	1,005	1,060	1,120	1,175	2,628
Burning time (hours)	12	12	13.5	13.5	27
average combustion temperature,°C	412	398.6	404	410	414
Average drying temp.	67.51	67	68	66	68
Initial moisture, % w.b	87	88	85	86	87
Final moisture % w.b	10	11	10.50	10	10

The drying temperature of every batch is from 66 to 68°C that proper for the drying ginger quality of color and moisture and the drying time is reduced due to the production process runs in night time by the combustor. The comparing in the drying energy sources is shown in table 2 for making a good selection to improve the process.

D. *The drying rate result*

Since the experiment of the conventional ginger batch or around 2,000 kg is valid with the calculation, the moisture content of the ginger is measured for finding the time as follow the table 1. In particular of the 3,980 kg of ginger which initial moisture content of 0.87 (w.b) that decreases to the final moisture after drying is 0.10 (w.b) in 27 hours as shown in Fig.5

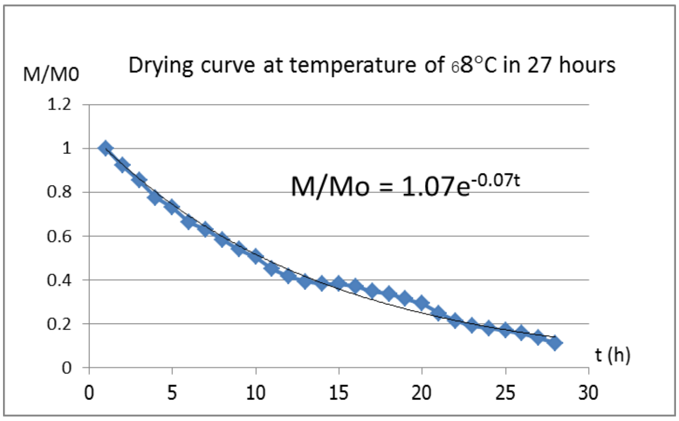

Fig.5 The drying ginger curve of the 3,980 kg batch

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In Fig.5 the drying rate of the ginger product is determined in exponential fitting curve according with the mathematical model of Henderson and Pebis [5]

$$MR = a\exp\left(-kt^{n}\right) \qquad (3)$$

Where *MR* is the moisture ratio (simplified to M/M_0)

M_0 is the initial moisture content in dry basis (d.b)

M is the moisture content at various time (d.b)

The fitting curve gives a = 1.07, k = -0.07 and n = 1.

The drying curve in the Fig. 5 is fitted by the mathematical model and reached the drying time of 27 hours continuously.

E. The relation of the fuel and the energy of the combustion

The wood boxes waste of the industry is used to be a good fuel for producing heat to the drying process. From table 1 the fuel in the experimental is exceeded than the calculation by the error of 0.1 due to the heat loss in the piping system. The comparison of energy or fuel to dry the ginger is presented in table 2 and the cost of energy in Thais money (baht)

TABLE II. HE EXPERIMENTAL RESULTS OF THE COMBUSTOR FUEL FOR VARIOUS GINGERS

Ginger products	Electricity		Heavy oil		Wood boxes	
	kWh	Cost	Litre	cost	kg	cost
1900 kg	4,807	14,423	544	10,886	1,096	1,800
2000 kg	5,117	15,352	579	11,587	1,166	1,800
2100 kg	5,407	16,221	612	12,243	1,232	1,800
2200 kg	5,672	17,018	642	12,843	1,293	1,800
3980 kg	11,533	34,599	1,305	26,113	2,389	2,400

Table 2 shows the comparison of the energy and the cost of the production process of the same ginger batch. The most expensive of the energy cost is electric drying and the second is heavy oil for burning to produce heat when compare with the wood boxes as a biomass fuel of the designed combustor. The cost of wood boxes is free due to the industry waste but the cost of wood boxes waste is the workers wage for feeding the fuel into the combustor. The benefits of the replacement fuel with the biomass industrial waste is the lower cost comparing with the electricity or the heavy oil and the reduction of removing the waste payment for cleaning the industry.

III. CONCLUSION

The industrial waste is used to be a biomass fuel for the combustor that design from the heat requirement from the ginger production. A solar tunnel dryer of the industry is used to produce the ginger product with the radiation but the time is too long cause to the high workers wage cost. The solar radiation transfers to heat by the area of 160 m^2 is 1,872 MJ per day therefore the combustor produce heat for supplying by the fuel from the waste. The highest batch of the ginger product for this industry is around 4,000 kg and requires heat of 8,138.22 MJ therefore the combustor design for producing heat from the waste fuel is depend on the average drying temperature, drying time and the fuel feed rate. The design volume of the combustor room for reaching the complete combustion is 4.5 m^3 and the maximum feed rate of 97.33 kg/s. The experiment set up to collect the data of the ginger production for checking the efficiency of the system and some heat loss of piping system in order to validate the design. Heat loss from the piping system from the data is average of 0.1 and the total efficiency of the combustor and the heat exchange is average of 0.19. Drying process is improved by the waste fuel combustor design for supplying heat in the night time and reducing the waste of the industry. These benefits present a cleaning industry of the friendly environment and high profit of the product trading due to the reduction cost of the energy.

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