80 kW Updraft Gasifier Performance Test using Biomass Residue Waste from Thailand Rural Areas

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Abstract—**This research presents the combustion test of Kanchanaburi's residue waste used in an 80kW updraft gasifier as biomass fuel. Three types of selected biomass were considered: corncob, bagasee, and straw. The 80kW updraft gasifier was designed, fabricated, and experimentally studied. In the gasifier, a variable speed centrifugal fan acted as a forced convection unit, which was installed near the combustion chamber and transferred air volume to the updraft gasifier stove. The experimental results show the temperature in each zone of the thermochemical processes. The gasifier was evaluated by comparing the performance of the 3 different biomass fuels. The average producer gas from the burning of corncob, bagasee, and straw was 2.31m^3/kg, 2.15m^3/kg, and 2.11m^3/kg respectively in the updraft gasifier. The recorded stove running times (h) for were 1.24, 1.2 and 1.05, respectively. The producer gas can be used to run a local cooking stove kiln with at normal rated heat generation successfully.**

Keywords-updraft gasifier; residue waste; heating value; thermal performance; corncorb; bagasee; straw

I. INTRODUCTION

Thailand is an agricultural country with agricultural residues of high potential [1], which can be used as renewable energy sources such as sugar cane, cassava, oil palm, rice, corn, bagasse, fiber and palm shell, rice husk, and corncobs. They can be used as fuel for generating electricity and heat. In the past, waste biomass was usually left to form organic fertilizers on the farmlands and sometimes it was burned. Biomass can be used as fuel because it provides heat at a level high enough to be considered as a source of heat energy. Biomass energy is therefore an interesting alternative energy source for substituting fossil fuels. Thailand has an area of approximately 6 million Rai (1Rai=1600m^2) for sugarcane cultivation representing an annual output of 6.8 million tons, according to the Office of Agricultural Economics in 2009. Most of the sugar cane is cultivated in the Central, Northeast and North. The major sugar cane cultivators are in Kanchanaburi, Nakhon Ratchasima, Khon Kaen, Nakhon Sawan, and Kamphaeng Phet. The cultivation of sugar cane takes only one year and the harvest takes 6-7 months. The harvesting period for old sugar cane takes 14 months. Corncobs are obtained from corn cultivation, in which an annual crop takes 3-4 months to harvest. There are two types of corn grown in Thailand: sweet corn for consumption and forage corn. Corn planting areas are provinces in the north and central regions. Corncobs can be used to make biomass fuel. Rice straw is agricultural waste or arising from rice cultivation. In 2008, it was estimated that the amount of discarded rice straw was approximately 4.63 million tons per year. The rice straw can also be used to make biomass fuel [1]. Gasification is the combustion of fuel, by limiting air or oxygen properly, into a flammable gas, called producer gas. This gasifier is a cylindrical combustion chamber shape. The fuel ignites from the top according to the upstream combustion process. The utilization of biomass from nearby agricultural waste material was investigated in this paper. A gasifier can be designed for utilizing a variety of fuels such as charcoal or scrapped wood. Agricultural waste such as corncobs or rice husk fuel can be used, but each source has different qualities, which depend on many factors such as fuel type, calorific value, and humidity. The important factor that has a significant effect on fuel quality is the amount of carbon contained in that fuel. Fuels with high carbon content will increase the calorific value. Fuel quality can be improved by increasing the carbon content, e.g. by applying coke on the chosen fuel type.

This work focuses on synthetic gas production, composting of hydrogen and methane gas. Our focus is both on gas production and on possible pathways to gas end use from biomass fuel in Kanchanaburi Province. This approach provides an overview of the potential for green synthetic fuels and discusses the technical feasibility of renewable fuel production, as well as its application in utilizing facilities. Particular attention is also paid to the design issues related to the quality of gas for energy conversion. Therefore, an 80kW updraft gasifier was constructed and experimentally investigated to find the combustion temperature in burning corncob, straw, and bagasse. The producer biomass gas contains hydrogen and carbon monoxide, which consist a source of energy capable of replacing LPG.

II. LITERATURE REVIEW

A. Gasification System

Gasification process is a process for converting carbon solid fuel components, such as wood, charcoal, coal, rice husk, sawdust, and combustible agricultural waste materials into combustion gas. Providing oxygen for reacting process will get

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the producer gas, which has carbon monoxide (CO), hydrogen (H_2), methane (CH_4) as main components along with various volatile substances. The efficiency of producer gas production depends on the production process and the quality of the fuels used. Renewable energy from producer gas has been widely used for 100 years, especially in Europe. A coal source can produce producer gas, which can be used in a wide range of industries. Producer gases can be used for cooking and heat or lighting provision to households. The objective of this research is to present a feasibility study of producer gas production derived from corncob, straw, and bagasse as a means of adding value to the crop. The two specific objectives of the current study are to provide the detailed design of an updraft gasifier that can be used with a variety of feedstocks and to test the quality and quantity of producer gas produced from the designed gasifier using local residue waste.

B. Biomass Technology

Today, biomass fuel is used as a commercial alternative to industrial fuel. Biomass can be derived from waste byproducts of the production process. Biomass fuel can be converted to energy in a number of ways. Figure 1 indicates the energy production technology for solid biomass.

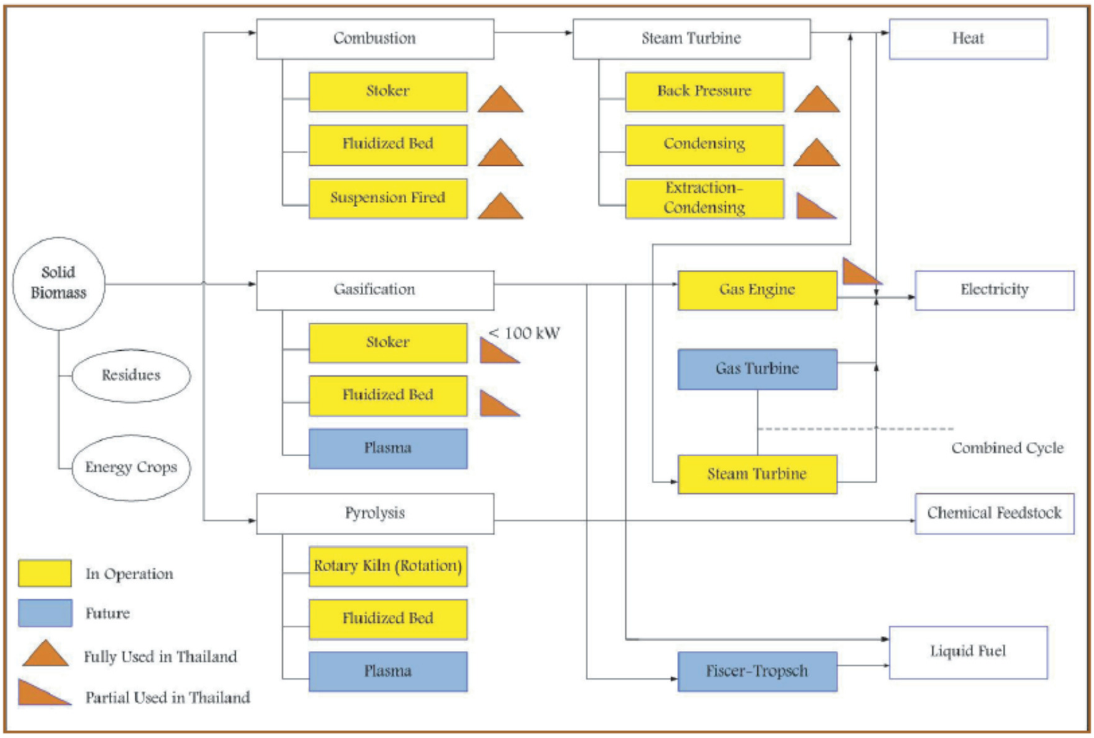

Fig. 1. Biomass fuel energy production technology.

Gasification Technology is the disintegration of hydrocarbons in a controlled state of oxygen at a fraction lower than the one which causes complete combustion (stoichiometric fuel air ratio). This will attain the main components of gas, specifically CO, H_2, and CH_4, which are termed as synthesis gas. The producer gas has originally a low calorific value, which gets higher if the reaction adds more oxygen to its content. The producer gas can be used as fuel for energy production or for the production of other forms of fuel. A gasification reactor can be divided into two systems: fixed bed and fluidized bed system. The fixed bed system is divided in 3 types:

- The updraft gasifier [2] is an air-flowing furnace. The air flows from the bottom and then upward. The fuel moves downward in a counter-direction to the current gasifier. This type of stove has a high thermal efficiency because the hot gas generated by the combustion zone flows through the fuel.
- The downdraft gasifier [3] is a downward direction gas-fired furnace. The air flows in the same direction with the fuel. It is also known as the co-current gasifier. In this type of furnace, the product of the pyrolysis zone flows through the combustion zone, where the temperature is high, it breaks down into gas before dropping from the stove. The obtained fuel gas has low tar, but has a high range of temperature, ranging from 300°C to 500°C.
- The cross draft gasifier is a cross-flow gas-fired furnace with fuel movement. The nature of the reaction layers, especially the combustion zone and the reduction zone, are closely related. Therefore, it can produce gas rapidly and simply. The combustion area is usually centered on the gas-producing furnace, but the combustion scope may be expanded if the air has a higher speed.

Biomass gasifiers are devices that convert gaseous biochemical fuels. Their products can be used for various purposes. There are three categories of gasifiers which produce production electric energy, heating, and hydrogen [4].

C. Fluidized-bed System

A fluidized-bed reactor (FBR) could be a combination of the two most common setups, mixed tank and pressed bed nonstop stream reactors [5]. It has fabulous warm and mass transfer characteristics. In FBR, cells are joined to solids within the frame of biofilm or granules [5, 6].

Authors in [7] conducted an experimental study of the updraft biomass gasifier using biofuels, which concentrated on testing and comparing the composition of syngas produced in a $0.221m^3$ fixed bed updraft gasifier from the combustion of coconut shell and biofuel briquettes. The gasifier was fired for 8h and readings were taken at regular intervals. It was concluded that coconut shell can be considered as a most suitable fuel for an updraft gasifier when compared to biofuel briquettes. Authors in [8] studied updraft gasification. In the updraft gasifier the downward-moving biomass was first dried by the up flowing hot product gas. After drying, the solid fuel settled, giving char particles which continued to move down to be gasified, and pyrolysis vapors which are carried upward by the up flowing hot product gas. The product gas from an updraft gasifier thus contains a significant proportion of tars and hydrocarbons, which contribute to its high heating value. There is interest in the cleaning of the updraft gas for electricity production, as low temperature tars are more reactive and thus easier to be removed, than the high-temperature tars produced in much lower amounts by downdraft and fluidized bed gasifiers. Authors in [9] designed and fabricated an updraft gasifier to run 15 to 18.6kW diesel engines. The gasifier was evaluated in the use of different biomass fuels. Completely Randomized Design (CRD) was used to statistically analyze the collected data. The average gas produced by burning rice husk, rice husk and sawdust, and sawdust produced $2.13m^3/kg$, $2.30m^3/kg$, and $2.54m^3/kg$ producer gas with 1.66, 1.78 and 1.90h engine running times, respectively. The produced gas was successfully used to run a 15kW single cylinder diesel engine with dual fuel (25% diesel and 75% producer gas) at rated rpm.

Producer gas consists of CO, H_2, CO_2, CH_4, traces of higher hydrocarbons such as ethane and ethylene, water vapors, N_2 (if air is the oxidizing agent) and various contaminants such as small char particles, ash, tar, and oil [10]. Authors in [3] studied the development of an equilibrium-based model of gasification of biomass by agricultural and forestry residues. They proposed an equilibrium-based model, developed by the commercial software Aspen Plus, of a co-current gasifier fueled by agriculture residues, which allows estimating the chemical composition and the heating value of the produced syngas. The prediction of such a model includes the main gaseous species, the yields of char and tar, and describes the gasification process through the mass and energy balances, the Water-Gas Shift, (WGS) and the methanation reaction. The model validation was carried out through the comparison with experimental data, concerning two kinds of biomass with different moisture content and different gasification conditions, for sixteen cases. The comparison between the results of the simulations and the experimental data exhibited a good agreement. Authors in [11] summarized an overview of the overall supply chain including production, transportation, storage, and end uses. Available fuel conversion technologies use renewable energy for catalytic conversion of non-fossil feedstocks to H_2 and syngas. The article shows how relevant technologies include thermochemical, electrochemical and photochemical processes. The quality of synthesis gas can be improved by catalytic reactions of CO and CO_2 methylation for the generation of synthetic fuel.

Various attempts have been made to control harmful emissions from engines. Authors in [12] conducted analysis of CO_2, CO, NO, NO_2, and PM particulates of a diesel engine exhaust. Authors in [13] carried out the analysis of a target gas system based on TDLAS & LabVIEW. They introduced target gas concentration detection techniques based on simulations of the gas detection system using the infrared absorption spectrum method. The detection of harmonics was measured with the wavelength modulation technique with the corresponding frequency signal and the gas absorption coefficient which can give the gas concentration, was obtained. Authors in [14] carried out mustard and cotton waste-based biomass gasifier simulation. They introduced a biomass gasifier model using Aspen Plus. The manufactured model was validated for four different types of feedstock. The developed model estimates a well-predicted composition of CH_4 and CO, H_2, and CO_2. Authors in [15] studied the techno-economic and greenhouse gas aspects of decentralized biomass gasification for electrifying the rural areas of Indonesia to reduce its dependence on fossil fuel power generation and to facilitate the electrification of its rural areas.

III. PROPOSED UPDRAFT GASIFIER

A. Design and Implementation

The scope of the design was to make a gasifier that can be utilized to test the possibility of producer gas production in Kanchanaburi biomass feedstock and be valuable for testing elective feedstocks. Corncobs, straw, and bagasse were chosen as fuels for the experiment. Due to its straightforwardness and flexibility, a settled bed, updraft arrangement was utilized (Figures 2-3). To permit longer unfaltering states when testing different feedstocks, a semi-continuous bolster framework was utilized. The sizes of components for this gasifier plan were chosen based on the change rate craved for the framework and the need to utilize off-the-shelf sizes of components. The transformation rate of biomass for the maker, the gas per square inch of cross sectional region within the gasification chamber was evaluated based on the change rate within the Sarah Rowland [16] updraft gasifier. The design aimed to make a gasifier that may be utilized to test the achievability of the assessed change rate of 10kg/h which was chosen since the volume was sensible and the gasification chamber had a 18cm breath pipe installed. The gasifier consists of five crucial components: container and feedstock wood screw, gasifier body, instigator and scrubber framework, back outline, and information collection framework. The gasifier unit was fabricated at the Faculty of Industrial Technology, Vallaya Alongkorn Rajabhat University and the control unit at Milada Part And Service Company Limited, Pratimtani Thailand. A sketch of the prototype is shown in Figure 2 and the complete fabricated stove can be seen in Figure 3. The advantage of the updraft gasifier is that no complicated components are required. A lot of biomass fuel can be combusted in not too high temperatures to provide high heating value producer gas. Its disadvantage is the low quality of producer gas because of tar and soot associated.

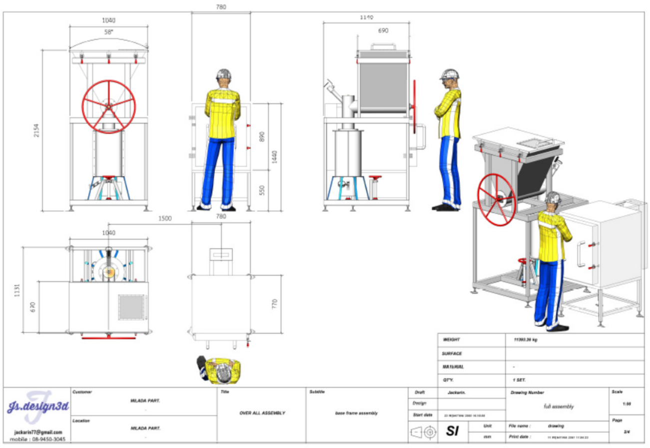

Fig. 2. Drawing of the 80kW gasifier.

Fig. 3. Updraft Gasifier 80kW prototype and its fabrication.

B. Thermal Efficiency

The thermal efficiency of the updraft gasifier system is the ratio of the energy derived from the produced synthetic gas of biomass fuel fed to the gas production system. The thermal efficiency equation of the system is [17]:

$$\eta_{gasifier}=\frac{HV_{Syngas}\times \dot{m}_{Syngas}}{LHV_{Biomass}\times FC_{Biomass}}\times 100 \quad (1)$$

where $\eta_{gasifier}$ is the thermal efficiency of the gasifier system, HV_{Syngas} is the calorific value of the gas producer (MJ/Nm^3), m_{Syngas} is the mass flow rate of the producer gas (m^3/s), $LHV_{Biomass}$ is the calorific value of the biomass (MJ/kg), and $FC_{Biomass}$ is the consumption rate of the biomass (kg/s).

C. Biomass Consumption Rate

Biomass fuel consumption of gasifier systems can be determined by measuring the amount of biomass fed to the system over time under the operating conditions. The fuel consumption rate can be obtained from:

$$FC_{biomass}=\frac{3600\times V_f\times \rho}{t} \quad (2)$$

where $FC_{biomass}$ is the rate of biomass fuel consumption (kg/h), V_f is the volume of biomass in the fuel storage tank, ρ is the density of the biomass (kg/m^3), and t is the time of use of biomass fuels (s).

IV. EXPERIMENTAL SET-UP

The moisture content of the biomass was determined by using ASTM Standard 1775-01. The biomass had 10.6±2.3% dampness substance (damp premise) amid three dampness substance tests conducted during the period when gasification tests were performed. Vitality substance was 12.99±0.02kJ/g employing an automatic bomb calorimeter, weight measuring, and compression to tablets by a pressing machine. The biomass was dehumidified by drying in the sun, and then its heating value was measured. Second desiccation biomass' heating value was determined by weighing 0.6-1.5g and compressing the oxygen gas into a vessel containing the biomass at a pressure of 400-440psi. Each sample took approximately 14min to analyze (Figures 4-5).

Fig. 4. Biomass preparation for heating value measurement.

Fig. 5. Bomb calorimeter for heating value measurements.

A. Gasifier Startup and Operation

A huge portion of the method included in testing a new gasifier design is deciding the suitable working methods for the framework and a given feedstock. After preparatory testing, the standard framework startup and operation methods for testing biomass feedstock were performed. The equipment was set up as shown in Figure 6. Biomass was loaded to the container and feedstock wood screw, then to the combustion chamber. Paper was fired in the chamber hole to start burning the biomass fuel.

The axial flow fan was turned on to permit the air flowing through the combustion chamber. The fan increases air draught and thereby combustion rate. The generated producer gas was checked by igniting. The control and display system shown in Figure 7 displays the temperature in each zone of the combustion (drying, pyrolysis gasification, and combustion zones). Another function of the control and display system is its ability to adjust the speed of the axial flow fan. The three types of selected biomass were corncob, bagasse, and straw (Figure 8).

Fig. 6. Gasifier startup and operation.

Fig. 7. Control and display system.

Fig. 8. Kanchanaburi selected biomass: corncob, straw, and bagasse.

B. Methodology

The updraft gasifier was set up on sunny days (September-October 2018) in the open air area. The container was filled with biomass and sealed. The Graphtec data logger was initialized and temperature recording was initiated. Throughout the operation, the scraper/agitator worked in conjunction with the feedstock wood screw to guarantee that feedstock moved to the gasification chamber. Both the steering wheel and the wood screw rotated counter clockwise. Wind speed was set to 8.12SCFM (0.23m^3/min). The combustion process took place after 3-5min until the two thermocouples reached temperature of approximately 40°C and smoke started to come out of the gas outlet. When the feedstock within the gasification chamber was clearly lit, the burn was expelled and the stove was fixed with the cap. Feedstock was supplied until the scraper/agitator met intense resistance, meaning the gasification chamber was full. The flow was balanced with the flow attempted at the time. Airflow rate varried from 8.12 to 20.13SCFM (0.23 to 0.57m^3/min). Ignition vessels were used as needed to maintain the flow within the feedstock. Gas tests were conducted when the formation temperature was stable and the flame was maximum and most stable. After the data of all the tests of the day were collected, the gasifier was cooled and cleaned. The amount of biomass that remained in the silo was measured.

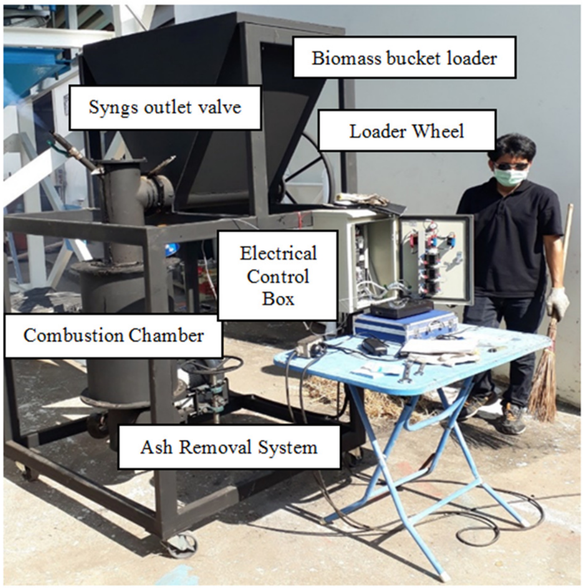

Fig. 9. The 80 kW updraft gasifier.

V. EXPERIMENTAL RESULTS

A. Physical and Chemical Biomass Properties

Before use the biomass was dried in the sun for a week for moisture reduction. Corncobs were brought from farmers around the corncob factory. The samples' size ranged between 14-15cm in length and 5-6cm diameter. The size of the bagasse was average with length of 13-15cm length and 5-6cm diameter. The length of straw was in the range of 17-20cm and the diameter in the range of 0.3–0.8cm. The mean density values for corncob, bagasse, and straw were 250kg/m^3, 260kg/m^3, and 240kg/m^3 respectively, and the mean heating values derived from the automatic bomb calorimeter measurement are shown in Table I.

TABLE I. HEATING VALUES

No.	Biomass	Avg. heating value (kcal/kg)	Avg. heating value (kJ/kg)
1.	Corncob	2,152.948	9,013.958
2.	Straw	1,588.911	8,433.003
3.	Bagasse	1,97.593	6,630.673

The output of ash content in the three feedstocks was 0.9% for corncob, 1.42% for bagasse, and 10.39% for straw.

B. Results of using Corncobs as Fuel

The experiment was carried out during 21-23 September 2018. The airflow rate fed into the combustion zone was controlled at 0.57m^3/min and 4.7kg of corncobs were added to the hopper. The test duration was 1h and 24min. During the test the temperature in the furnace body in each combustion zone was measured using a thermocouple. The K-type thermocouple T_1, T_2 and T_3, (combustion, reduction, and pyrolysis temperature) are displayed on the control panel of the furnace. Temperature thermocouples T_4, T_5 and T_6 were used for measuring and collected data on a GL-820 data logger. The experiment results are shown in Figure 10. It was found that the maximum combustion temperature was 716.1°C after 1h and 24min and the initiation temperature of the gas was 260.4°C after 20min.

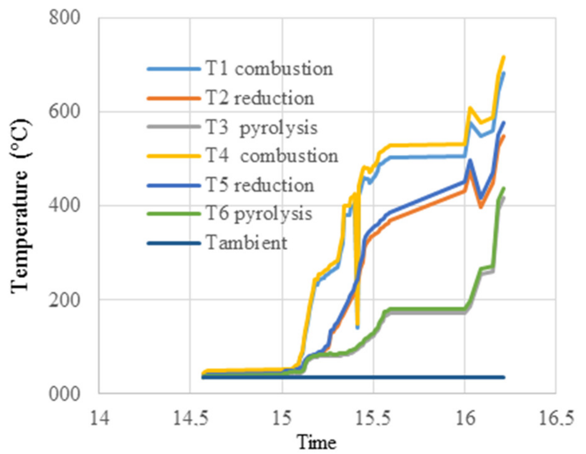

Fig. 10. The temperatures of burning corncob during 2018, Sept,. 21-23.

C. Results of using Straw as Fuel

The experiment was conducted on 28-30 September 2018. In this experiment, the airflow rate into the combustion zone was equal to 0.57m^3/min and 4.5kg straw was loaded. The experiment period was 1h and 20min.

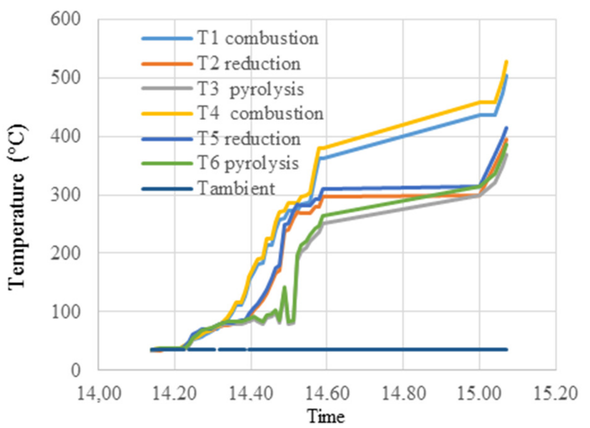

Fig. 11. Graph of the burning straw, 2018, Sept., 28-30.

As before T_1, T_2 and T_3 were displayed on the control panel display for data acquisition of the furnace body and T_4, T_5 and T_6 were measured and stored into a data logger. The maximum combustion temperature was 528.15°C after 1h and 20min and the gas initiation temperature was 159.6℃ after 26min as can be seen in Figure 11.

D. Results of using Bagasse as Fuel

The experiment was conducted during October 5-7, 2018. In this experiment, the airflow rate was 0.57m^3/min and 4.5kg of bagasse was applied. The experiment period was 1h and 5min. Again, T_1, T_2 and T_3 were displayed on the control panel display and T_4, T_5 and T_6 were measured and stored into a data logger and the result can be seen in Figure 12. The maximum combustion temperature was 520.8°C after 65min and the gas initiation temperature was 199.5℃ after 19min.

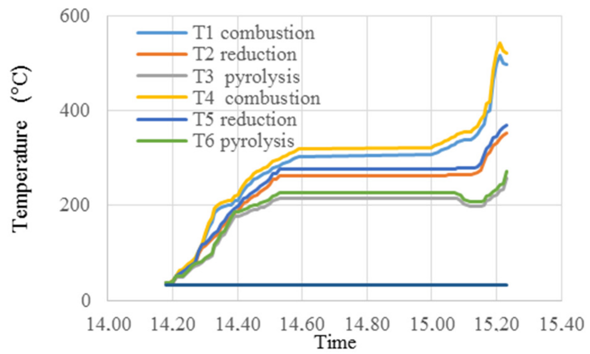

Fig. 12. Graph of the burning bagasse, 2018, Oct., 5-7.

VI. CONCLUSION AND FUTURE SCOPE

The results of the corncob incineration experiment found that at airflow rate of 0.57m^3/min, the maximum temperature of the furnace during the combustion was 716.1°C. The gas initiation temperature was 260.4°C after 20min when adjusting 100% airflow rate into the furnace as the maximum value, resulting in the fastest possible amount of oxygen to help burn the fuel. Regarding straw burning, the results of the experiment showed that for airflow rate of 0.57m^3/min, the maximum temperature of the furnace during combustion was 528.15°C. The gas temperature was 159.6°C after 26min. The results of the bagasse incineration experiments showed that the maximum temperature of the furnace during combustion was 520.8°C and the gas initiation temperature was 199.5°C after 19min. There is high loss of heat from gas production. Using LPG as fuel will produce higher heating values than corncobs. Burning corncob produced less smoke than burning straw and bagasse. The heating value of corncob is higher than that of straw and bagasse, but it produces more tar. Corncob and straw can be used in a ceramic kiln, but a gas filter should be added to clean the gas. The calorific value of bagasse is relatively low and it must be cut down in order to reduce its size, so it is not suitable to be used as a fuel.

The bomb calorimeter experiment found that corncob's heating value of 9,013.958kJ/kg was the highest, followed by straw with a heating value of 8,003.433kJ/kg, while bagasse had the lowest heating value of 6,673.630kJ/kg. These biomass-heating values correspond to the combustion temperature in the gasifier's combustion chamber mentioned above. For comparison, woodchips used as fuel in the development and performance evaluation of a biomass gasification system for ceramic firing process have heating value of about 12-15MJ/kg [18]. It can be concluded that Kanchanaburi province has the potential of producing biomass energy with sources like as corncobs and rice straws that can replace the consumption of LPG gas.

Some of the issues the gasifier faces could be dealt with in as a next step. An automatic conveyer for biomass loading system can be installed for operation convenience. The stack could be extended in order to eliminate smoke rapidly during the operation. New types of locally available biomass fuel could be studied.

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