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Experimental Survey of Co-Combustion and Gasification of Biomass Furnace

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Abstract

When researching, designing and manufacturing a model of Co-combustion and gasification of biomass furnace with the goal of achieving the amount of air supplied for the combustion process, here the first stage is combustion/burning process, so there is excess oxygen, which means excess air $\lambda > 1$.The next stage is gasification, i.e. anaerobic combustion, so the oxygen content of the combustion process is anoxic, which means that the excess air is $\lambda < 1$. It is the combination of such simultaneous combustion and gasification that the energy conversion process will achieve higher thermal efficiency. In this report, we present a summary of experimental research results on the "model" of the furnace and simultaneous gasification, the results of evaluating the quality of the gas generated from the combustion process, the achieved flame temperature inside the furnace, the heat capacity of the furnace and the selection of the air flow provided for the combustion process. With the type of furnace and gasifier at the same time in this research, it can be used for drying agricultural products of household scale, or group of households, or used for medium scale at agricultural product processing establishments/enterprises and suitable for rural and/or mountainous conditions in Vietnam.

Keywords: Co-combustion and gasification furnace, biomass, energy efficiency, emissions

1. Introduction

Vietnam is an agricultural country, every year after the harvest season, the amount of biomass residues from agricultural and forestry by-products that have not been used is still high. Most of this residue is actually not much used by people, or used ineffectively and is often discarded, causing environmental pollution. Meanwhile, the processing facilities (drying) of agricultural products are still using fossil fuel sources such as coal as the main source, but energy from fossil fuel sources (coal, oil, natural gas, etc.) is increasingly depleted and causes environmental pollution. Therefore, the use of renewable energy sources from biomass is necessary. It meets the current demand for the application of renewable energy sources to replace traditional energy sources for use in drying agricultural products. Household scale for rural and mountainous areas as well as medium-sized processing establishments and enterprises is essential. Currently, agricultural product processing facilities mainly use fuel from direct furnace, but with this type of direct furnace, the thermal efficiency of the furnace is not high and the combustion process will cause environment pollution. Besides, there are also some facilities that use fuel from gasification furnaces to get indirect heat for drying agricultural products. Although this model of furnace has high thermal efficiency and does not harm the environment, the investment cost is high. Therefore, the research of Co-combustion and gasification furnace model for applying into practice will promote economic efficiency and improve energy conversion efficiency. This also has significant impacts in terms of science and practice adoptation [1- 3].

Fig. 1. Biomass of corn cob and bark after processing peeled wood

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Table 1. Physio-chemical properties of corn cobs and waste peeled wood.

Composition (%)	(C)	(H)	(O)	(N)	(S)	(a)	(w)	Hu (Mj/kg)	Density (kg/m^3)
Corn cob (11%)	50.29	7.01	28.04	0.74	-	2.93	11.0	16.983	356
Corn cob (25%)	42.38	5.91	23.63	0.63	-	2.47	25.0	13.918	558
Waste-peeled wood (26%)	41.81	5.83	23.31	0.62	-	2.43	26.0	13.699	654
Waste-peeled wood (50%)	28.25	3.93	15.75	0.42	-	1.64	50.0	8.446	785

2. Materials, Methods, Measuring Devices, and Research Equipment

- Research materials (Fig. 1): In this research, the research materials are locally available biomass used as fuel for combustion/gasification. In this study two groups of biomass are mentioned: i- Dry biomass with the moisture of 11-25% (in this case, the cob); ii- Fresh biomass with the moisture of 26-50% (here is the bark after processing peeled wood/ waste peeled wood) [1, 3]. For corn cob and waste peeled wood that has special physical, chemical possibilities, there are physical, chemical features, especially the components of materials such as carbon (C), oxygen (O), hydro (H), nitrogen (N), sulfur (S), ash (a) and low heat value of Hu material are shown in Table 1 [4-11].

- *Research method*: in this research, the author uses an experimental research method combined with analysis and synthesis of experimental data to evaluate the quality of syngas generated from the combustion process and heat capacity obtained from the furnace. These act as a basis for selecting the optimal operating modes for the furnace.

- *Measuring equipment in the research*: measuring devices (Fig. 2) used in the experiment including a- bench scale to determine mass (VN); b- gun-type handheld temperature measuring device (Ebro - Germany); c- flow meter and air velocity (Testo - Germany); d- motor speed control inverters; e- clamp meter to measure power consumption (Germany); f- pre-fuel moisture meter. In addition, there are temperature sensors that measure the temperature inside the oven for measurement, survey and inspection. These measuring devices have a great influence on the accuracy of experimental results [1, 3].

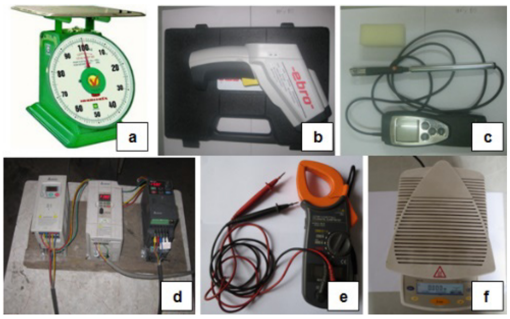


Fig. 2. Measuring equipment for experimental research

Table 2. Main technical parameters of experimental equipment

Specifications	Symbol	Unit	Value
CALCULATE SPECIFICATIONS OF FURNACES			
Heat capacity	Q'	kW_{th}	1,388.2
Thermal efficiency	η_{bd}	%	68.0
Grate area in furnace	F_{grate}	m^2	0.44
Combustion chamber volume	V_{bd}	m^3	0.55
Furnace diameter	$D_{LĐ}$	m	0.75
Amount of fuel consumed	m'_{NL}	kg/h	200
Required amount of air Fan must provide	V_0	m^3/h	1,100
CALCULATION PARAMETERS OF INCLUDE FAN			
Electric motor power	N	kW_{el}	1.1
Number of wings	z	wing	12
Wing foot diameter	D_1	mm	100
Wing tip diameter	D_2	mm	250
Wing width	b	mm	40
Actual amount of air the fan must deliver	$V_{reality}$	m^3/h	1,001.4
Air volume according to Fan characteristic curve	$V_{fan\ selector}$	m^3/h	3,600
Total pressure	ΔP	mmH_2O	220
Kinematic coefficient of fan	k	-	0.4
Centrifugal fan efficiency	η_{fan}	-	0.7
An number Д4–70N°3	N° 3	-	-

- *Research equipment*: the research equipment mentioned in this article is the Co-combustion and gasification furnace of corn cob biomass and bark after peeling wood (Fig. 3). The main technical parameters of the experimental equipment are shown in Table 2 [1-3].

Fig. 3 shows the schematic diagram of the experimental furnace. The specific operation process of the furnace is as follows: biomass fuel (6) is filled into the internal volume of the furnace (2), then we "burn the bait" right on the surface of the biomass fuel (6) (reverse combustion). After burning for 5 - 10 minutes, the biomass layer (6) on the surface will be sharp and continue to burn. According to reverse combustion principal, the burning process will produce smoke (flue gas). The fuel has not completely burn in the combustion process because of lacking oxygen (not enough oxygen). Therefore, this process can also be called the anaerobic combustion process and as a result, it can produce syngas. In the synthesis of syngas, there are combustible gas components in syngas which are CH_4, H_2, and CO, these gases also rise in the direction of the smoke (flue gas) exit. Meanwhile, the air has been blown back from the bottom up by the blower fan/furnace fan (1), the amount of air supplied to the furnace is partly in that it is provided to the furnace from the bottom to blow up. Thanks to this gas flow, the syngas generated in the furnace in the fuel combustion zone are up, and a part of the air (including oxygen) is supplied/blown to the upper part of the reactor's reaction chamber to support the combustion of gases. Burning CH_4, H_2, and CO in syngas will increase the thermal efficiency of the device. Thus, this device will be first combustion (reverse combustion) then gasification.

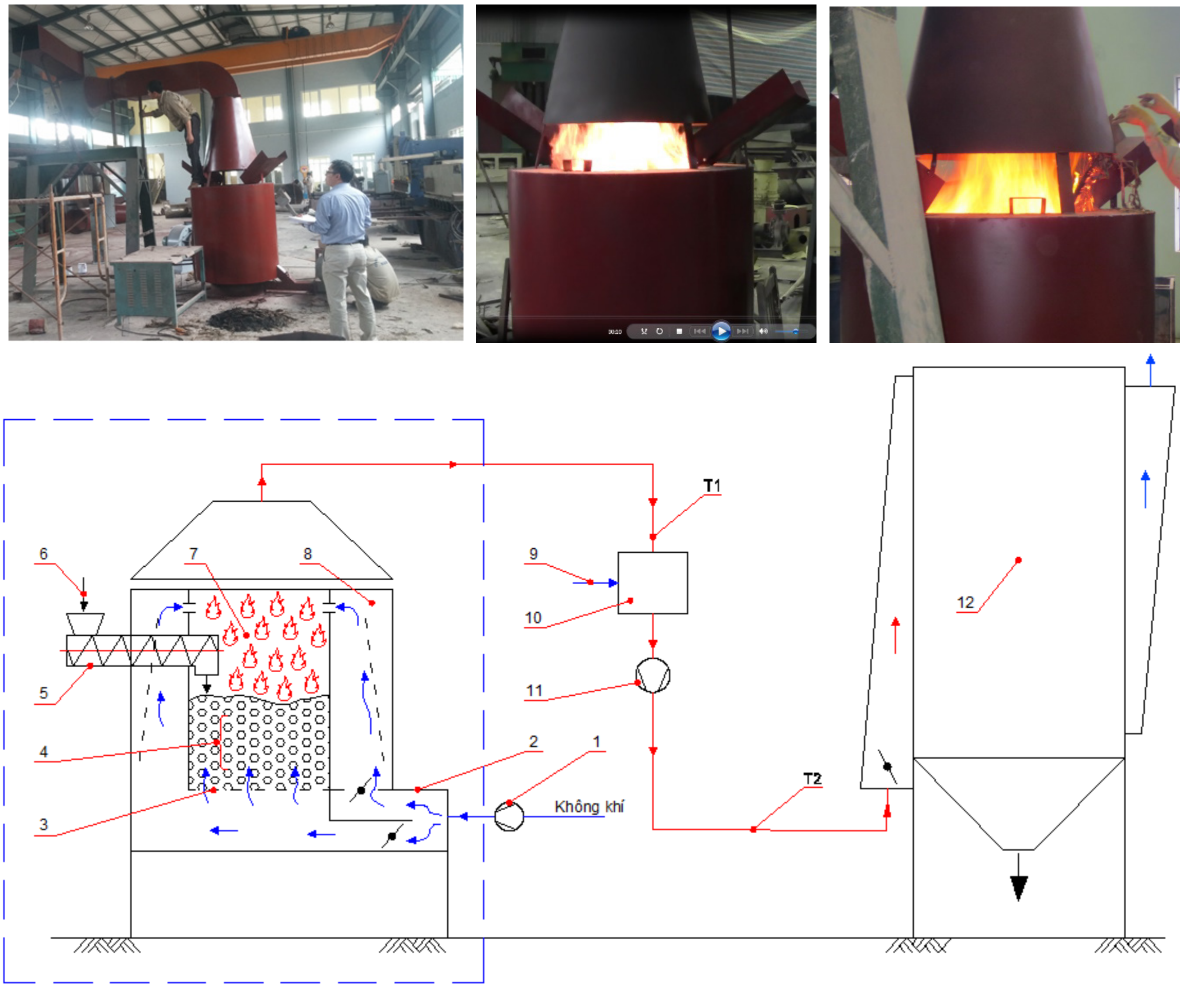


Fig. 3. Schematic diagram of the experimental furnace. 1- Furnace fan; 2- Co-Combustion and Gasification furnace; 3- Grate furnace; 4- Three zones: the combustion/oxidation zone, the pyrolysis zone and the reduction zone; 5- Screw conveyor; 6- Fuel; 7- Combustion of syngas; 8- Air chamber; 9- Air; 10- Mixing chamber; 11- Drying fan; 12- Drying system/Dryer; T1- Flame temperature; T2- Drying agent temperature.

3. Research Results and Discussion.

The process of testing the biomass furnace sample was tested on the basis of testing the combustion process with two different types of burning materials (corn cob, bark after processing peeled wood) as shown in Fig. 1.

Details of the test results determine the furnace temperature, the required fan/air flow and the amount of furnace heat capacity, the percentage of fuel consumed that the furnace needs to provide. That alls are presented in Table 3 [3].

Table 3. Table of furnace testing data

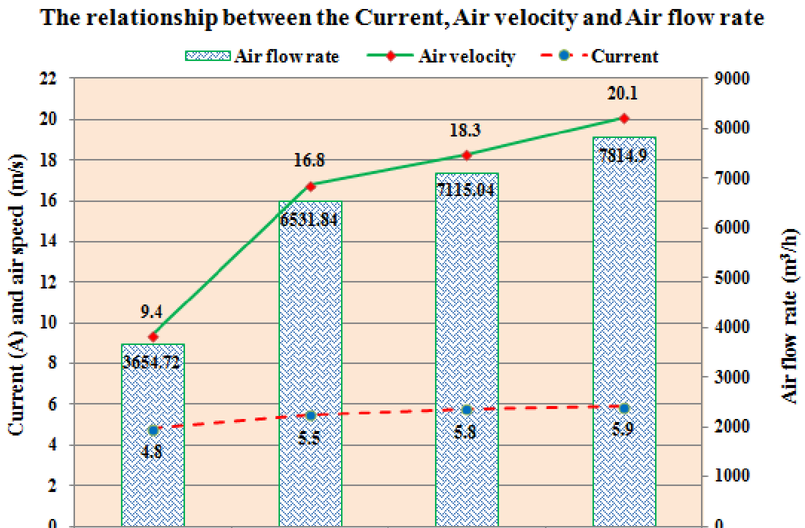
Specifications	Unit	Result	
		Corn cob	Bark
Material moisture	%	11-25	26-50
Flow of furnace fan for combustion	m^3/h	1,100	1,100
Fuel consumption rate	kg/h	200	190
The temperature of the furnace	^oC	690	580
Heat capacity of the furnace	kW_{th}	935	930

On the basis of the furnace test, in addition to the measured results presented in Table 3, the author also measured some results of assessment of air velocity and flow through a graph showing the relationship between velocity and air flow. The air flow when surveyed in different throttle opening modes, corresponding to levels from 25 %, 50 %, 75 % and 100 % are presented as shown in figures from Fig. 4 to Fig. 6 [3].

The graph Fig. 4 shows that the air velocity for the drying fan changes rapidly when expanding the throttle valve: when opening the throttle valve at the maximum state of 100% compared to the minimum level of 25%, it shows that the speed of the throttle valve is increased. The air at this time increased about 2.14 times, also equal to the rate of increase of the air flow, while the current increased only 1.22 times [3].

Fig. 5 shows that the air velocity for the furnace fan changes from 11.81 (m/s) corresponding to the 25% throttle opening level to 25.25 (m/s) corresponding to the open level throttle 100%, an increase of about 2.14 times is also equal to the rate of increase of air flow. But in this experiment the current increases about 1.5 times between the two states [3].

The graph in Fig. 6 shows that this is the experimental data synthesized from Fig. 4 and Fig. 5. The result show the relationship between the quantities such asair flow, air velocity, furnace fan current and current of the drying fan when the throttle valve varies from 25% to 100%. At this time, the rate of increase of the current for the furnace fan and the drying fan does not change compared to the two cases mentioned in Fig. 4 and Fig. 5. In terms of air flow, it only increases 2.04 times instead of 2.14 times as mentioned above, because now both fans are running at the same time, similar to the connection between two fans through the furnace and the dryer, Thus, it is affected by the resistance of the system and the amount of moisture released during drying [3].



	Throttle air ratio 1 (25%)	Throttle air ratio 2 (50%)	Throttle air ratio 3 (75%)	Throttle air ratio 4 (100%)
Air flow rate	3654.72	6531.84	7115.04	7814.9
Air velocity	9.4	16.8	18.3	20.1
Current	4.8	5.5	5.8	5.9

Fig. 4. Graph showing the relationship between air velocity and air flow when testing with drying fan

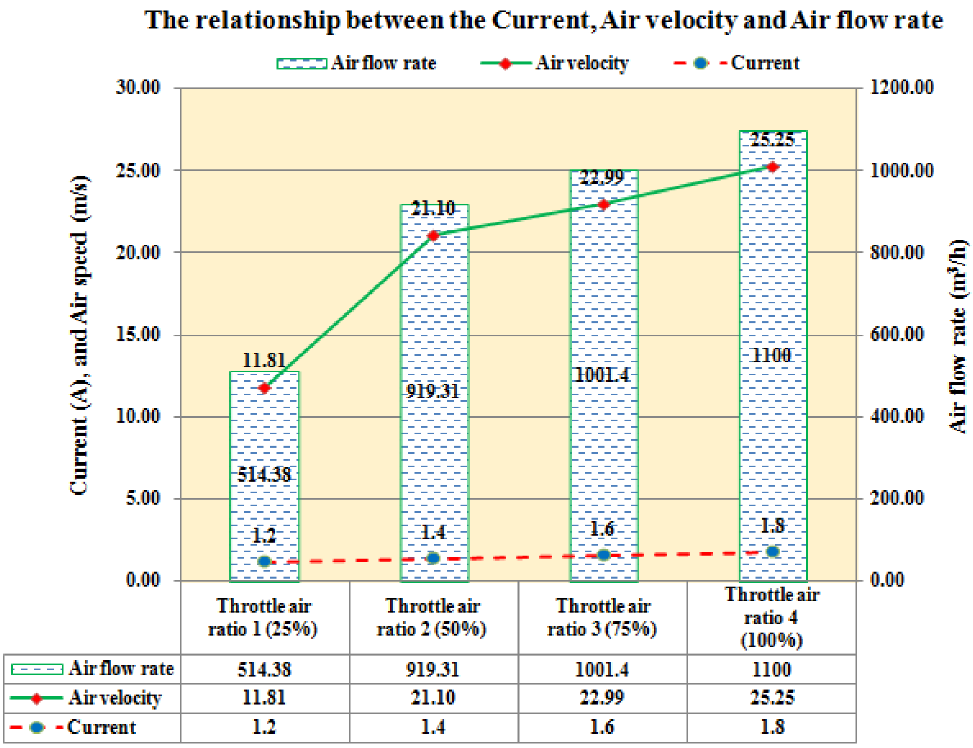


Fig. 5. Graph showing the relationship between air velocity and air flow when testing with furnace fan

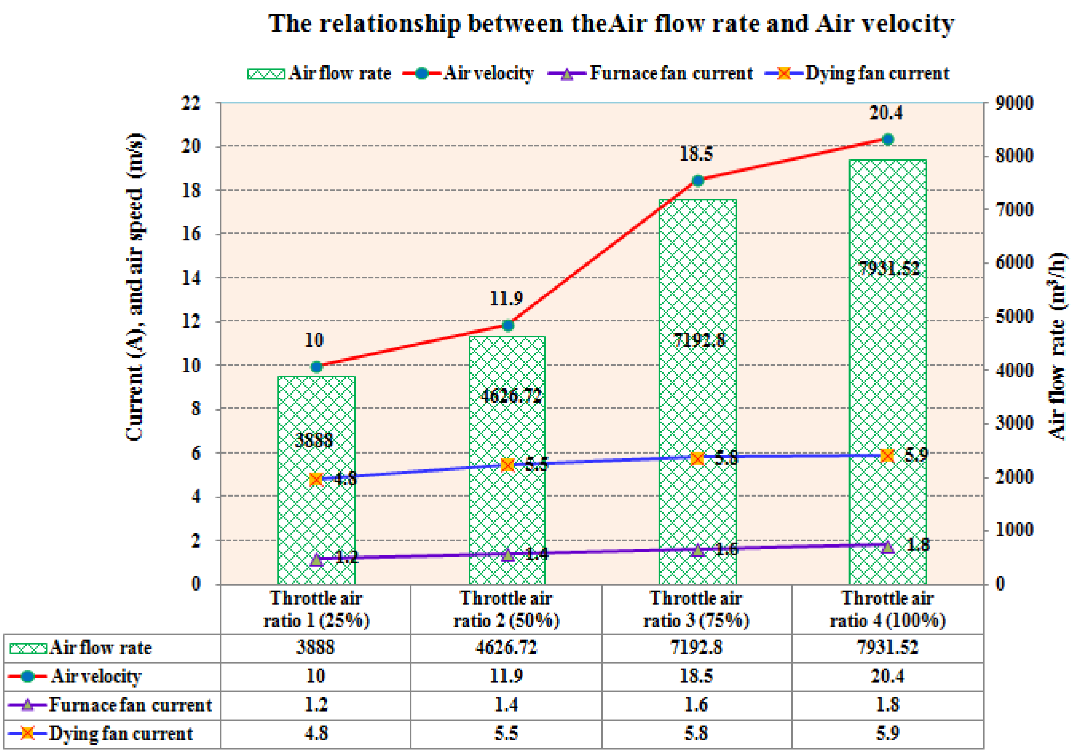


Fig. 6. Graph showing the relationship between air velocity and air flow when testing using furnace fan and drying fan

Table 4. Investigation results of syngas with corn cob when moisture varies (fixed fan frequency 40Hz) .

Operating time (minutes)	Corn cob moisture at 11.24%			Corn cob moisture at 18.6%			Corn cob moisture at 24.3%		
	Quality of gas produced (%)			Quality of gas produced (%)			Quality of gas produced (%)		
	CO	CH_4	H_2	CO	CH_4	H_2	CO	CH_4	H_2
0	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-
90	16.16	3.14	12.17	18.13	3.04	12.04	15.61	3.23	11.64
180	18.21	3.64	12.50	18.75	3.45	12.47	16.18	3.01	12.10
270	17.16	2.63	11.43	12.54	2.53	11.37	17.01	3.59	12.94
360	17.99	3.10	11.84	17.64	3.07	11.74	16.88	3.09	12.22
450	16.69	3.38	12.89	18.51	3.28	12.49	16.23	2.75	11.70
480	17.01	3.44	12.48	17.38	3.42	12.38	16.44	2.98	12.03
	17.20	3.22	12.22	17.16	3.13	12.08	16.39	3.11	12.10
The average value	Flame temperature is 690 ^{0}C			Flame temperature is 680 ^{0}C			Flame temperature is 600 ^{0}C		

The testing and evaluation of the quality of the combined furnace when gasification of biomass is simultaneously evaluated through the quality of the gas generated from the furnace, the temperature achieved by the furnace, thereby serving as a basis for evaluating the heat capacity of the furnace. Experimental process through many modes with the change of fuel moisture content, change of air flow supply for combustion process through changing the furnace fan frequency with different levels, the results are presented in Table 4.

Table 4 is the experimental results of the furnace and simultaneous gasifier with the corn cob fuel as the fuel with varying moisture content corresponding to the furnace fan mode with a constant value of 40 Hz. The combustion process takes place continuously for a period of 480 minutes (8h), continuously monitoring after the first 90 minutes, the furnace begins to have stable gas components, then we measure. Through the gas analyzer, experimenting with the moisture content of the fuels varying at different levels, the experiment found that in the case of the corn cob moisture content of 11.24%, the average quality of gas produced achieved is the highest and most stable (CO: 17.20 %; CH_4: 3.22 %; H_2: 12.22 %). In this case, the highest flame temperature reaches 690 ^{0}C.

Experimental results of the furnace and simultaneous gasifier with the corn cob fuel and a moisture content of 12% corresponding to the furnace fan mode have values ranging from 30 to 50 Hz as shown in Table 5. Continuous combustion for a period of time 480 minutes, after the first 90 minutes, the gas components are stable, at this time we measure and get data. With the variable furnace fan speed, through the gas analysis, it was found that in the case of the furnace fan operating at 40 Hz, the quality of the gas produced reached the highest, most stable average value (CO: 17,.04%; CH_4: 3.10%; H_2: 12.01%). In this case, the highest flame temperature reaches 650 ^{o}C. Through 2 experimental cases with the corn cob burning material, as the above results found, with the corn cob having moisture content from 11-12 % and the furnace fan mode at 40 Hz, the furnace operates stably, giving high quality. The amount of gas produced is of the best quality, and the temperature of the flame produced reaches the most optimal value.

Table 6 is the experimental results of the simultaneous gasification furnace with the burning material being bark after processing peeled wood, experimenting with materials with variable moisture content and keeping the furnace fan mode constant at 40 Hz. During the continuous burning period of 480 minutes, also in the first 90 minutes, the furnace operated stably and began to monitor the gas components generated at this time. Through gas analysis, with varying levels of fuel moisture, it was found experimentally that in the case of bark moisture content of 26.7%, the average quality of gas produced was the highest and stable. (CO: 14.75%; CH_4: 2.8%; H_2: 10.89%). In this case, the highest flame temperature reaches 500^{o}C.

Table 5. Investigation results of syngas with corn cob when frequency fan varies (fixed moisture 12%).

Operating time (minutes)	Frequency of primary fan at 30 Hz (equivalent air flow rate: 660 m^3/h)			Frequency of primary fan at 40 Hz (equivalent air flow rate: 880 m^3/h)			Frequency of primary fan at 50 Hz (equivalent air flow rate: 1.100 m^3/h)		
	The quality of the gas produced (%)			The quality of the gas produced (%)			The quality of the gas produced (%)		
	CO	CH_4	H_2	CO	CH_4	H_2	CO	CH_4	H_2
0	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-
90	15.99	3.11	12.04	17.94	3.01	12.04	15.45	3.19	11.76
180	17.83	3.61	12.38	16.90	3.41	12.35	16.01	2.98	12.22
270	16.98	2.61	11.22	14.38	2.51	11.25	16.84	3.56	13.07
360	17.81	3.07	11.43	17.46	3.04	11.62	16.71	3.06	12.22
450	16.52	3.34	12.76	18.33	3.24	12.56	16.06	2.72	11.70
480	16.84	3.40	12.06	17.21	3.38	12.26	16.28	2.95	12.03
The average value	16.99	3.19	11.98	17.04	3.10	12.01	16.23	3.08	12.17
	Flame temperature is 620 ^{0}C			Flame temperature is 650 ^{0}C			Flame temperature is 600 ^{0}C		

Table 6. Investigation results of syngas with peeled wood when moisture varies (fixed fan frequency 40 Hz).

Operating time (minutes)	Waste peeled wood moisture at 26.7%			Waste peeled wood moisture at 34.5%			Waste peeled wood moisture at 42.3%		
	The quality of the gas produced (%)			The quality of the gas produced (%)			The quality of the gas produced (%)		
	CO	CH_4	H_2	CO	CH_4	H_2	CO	CH_4	H_2
0	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-
110	14.05	2.91	10.48	13.27	2.75	9.89	12.49	2.58	9.31
180	14.56	2.71	10.89	13.75	2.56	10.29	12.94	2.41	9.68
270	15.31	3.23	11.65	14.46	3.05	11.00	13.61	2.87	10.35
360	15.19	2.78	11.00	14.35	2.63	10.39	13.50	2.47	9.78
450	14.61	2.48	10.53	13.80	2.34	9.95	12.98	2.20	9.36
480	14.80	2.68	10.83	13.97	2.53	10.23	13.15	2.38	9.62
The average value	14.75	2.80	10.89	13.93	2.64	10.29	13.11	2.49	9.68
	Flame temperature is 500 ^{0}C			Flame temperature is 470 ^{0}C			Flame temperature is 460 ^{0}C		

Table 7. Investigation results of syngas with peeled wood when frequency fan varies (fixed moisture 26%).

Operating time *(minutes*	The frequency of the primary fan is at 30 Hz (equivalent air flow rate: 660 m^3/h)			The frequency of the primary fan is at 40 Hz (equivalent air flow rate: 880 m^3/h)			The frequency of the primary fan is at 50 Hz (equivalent air flow rate: 1,100 m^3/h)		
	The quality of the gas produced (%)			The quality of the gas produced (%)			The quality of the gas produced (%)		
	CO	CH_4	H_2	CO	CH_4	H_2	CO	CH_4	H_2
0	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-
110	13.35	2.76	9.96	14.33	2.97	10.69	12.65	2.62	9.43
180	13.83	2.57	10.35	14.85	2.76	11.11	13.10	2.44	9.80
270	14.54	3.07	11.07	15.62	3.29	11.88	13.78	2.91	10.49
360	14.43	2.64	10.45	15.49	2.84	11.22	13.67	2.50	9.90
450	13.88	2.36	10.00	14.90	2.53	10.74	13.15	2.23	9.48
480	14.06	2.55	10.29	15.10	2.73	11.05	13.32	2.41	9.75
The average value	14.02	2.66	10.35	15.05	2.85	11.11	13.28	2.52	9.81
	Flame temperature is 520 ^0C			Flame temperature is 580 ^0C			Flame temperature is 470 ^0C		

Experimental results of the furnace with the burning material being bark with a moisture content of 26% with a change in furnace fan mode from 30 to 50 Hz as shown in Table 5. Continuous burning process for a period of 480 minutes, in about for the first 90 minutes, the furnace operates stably and produces gas. At this time, it is time to start monitoring the gas components produced. With the variable furnace fan speed, through gas analysis, it was found that in the case of the furnace fan operating at 40 Hz, the quality of the gas produced reached the highest, most stable average value (CO: 15.05%; CH_4: 2.85%; H_2: 11.11%). In this case the highest flame temperature reaches 580 ^oC. Through 2 experimental cases with bark fuel as the above results, it was found that with the bark having a moisture content of 26-50% humidity at the frequency mode of the furnace fan of 40 Hz, the incinerator operates stably. The quality of the gas produced is of the best quality, and the temperature of the flame produced reaches the optimal value.

4. Conclusion

Through the research results as above, it is shown that factors such as moisture content of fuel and gasification materials, flow of blower supplied to the furnace, etc. are the main factors that greatly affect the heat supply process from the furnace, in other words, they affect the heat capacity of the furnace (Table 3). Experimental results of the Co-Combustion and Gasification of Biomass Furnace with corn cob burning material with a moisture content of about 12%, the furnace fan air flow providing 880 m^3/h (corresponding to a fan frequency of 40 Hz), giving us the best quality of gas produced, (CO: 17.20%; CH_4: 3.22%; H_2: 12.22%), the highest flame temperature in the furnace reaches 690 ^oC. Experimenting with an incinerator with bark fuel with a moisture content of about 26%, the furnace fan's air flow provides 880 m^3/h (the fan frequency is 40 Hz), giving us the best quality of gas produced (CO: 15.05%; CH_4: 2.85%; H_2: 11.11%), the highest flame temperature in the furnace reaches 580 ^oC. The above results show that the influence of the parameters of material moisture and air flow on the ability to generate heat efficiency of the furnace is different, in which the moisture parameter of the raw materials has more influence compared with the change in blower flow (Table 3 to Table 7). In addition, when changing the opening state of the throttle valve of different fans, the ratio of change between air speed and air flow is the same, but the ratio of measured current changes differently, no longer equivalent according to the throttle opening ratio.

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