



# The Effect of Biomass Shapes on Combustion Characteristic in Updraft Chamber

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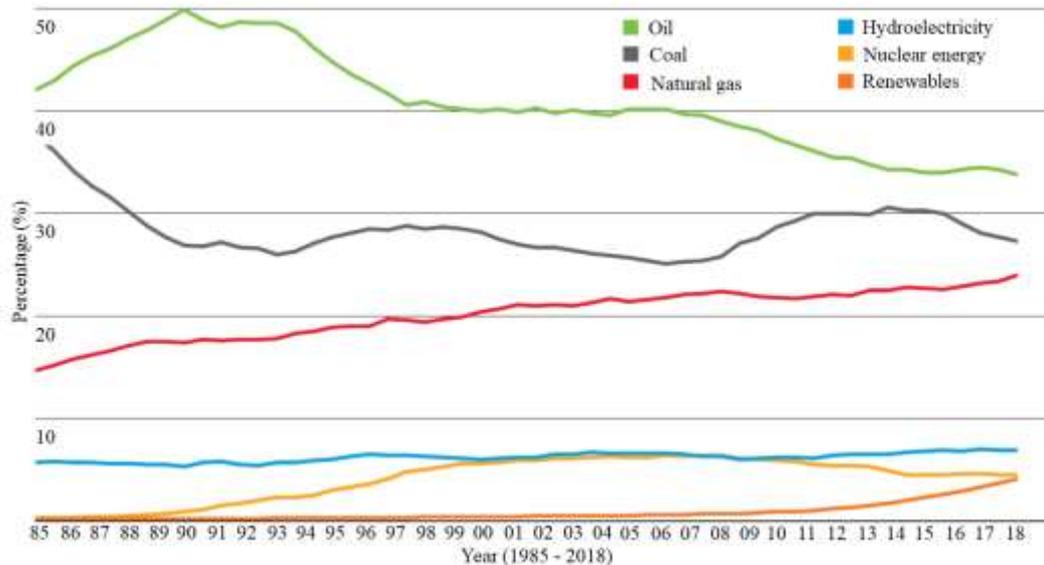
**Abstract:** Combustion of agricultural residues and wastes for energy applications is still popular. However, combustion of biomass with different shapes leads to many side effects such as agglomeration, emission and incomplete combustion. The aim of this study was therefore to investigate the effects of biomass shapes on combustion characteristics in an updraft combustion chamber. The rubber wood chip, coconut shell, oil palm empty fruit bunch, corn straw, rubber wood sawdust, and mixed palm cake were used as fuel and they were categorized as 3 shapes namely, chip shape, fiber shape, and powder shape. The biomass sample was combusted in simple cylindrical shape combustion chamber. The diameter of combustion chamber was 20 cm and its height was 160 cm. The biomass sample (moisture content below 20%) with amount of 1 kg was used to perform the experiment. The ambient air that had velocity of 0.50, 0.75 and 1.00 m/s (corresponding to an equivalence ratio of 1-3.5) was supplied to combustion chamber. The temperature at different positions along combustion chamber height and the properties of flue gases (carbon monoxide) were then measured. The results showed that the biomass shape had effect on combustion characteristics. Combustion of fiber shape biomass led to low combustion temperature, while the carbon monoxide in flue gases was high. This indicates the improper combustion process. The chip shape biomass was well combusted at a higher air velocity and the flue gases had lowest carbon monoxide. The highest combustion temperature was obtained from combustion of powder shape biomass. However, it led to the problem of unburned biomass such in case of sawdust. This is because the sawdust powder was carried from combustion chamber before burning completely.

**Keywords:** Updraft chamber, combustion, biomass, waste agriculture

## 1. Introduction

Shares of global primary energy consumption by different resources since 1885 to 2018 are shown in Figure 1. It is seen that the oil remains the most used fuel in the energy mix. Coal is the second largest fuel. However, they tend to decrease every year [1]. The natural gas is the third largest fuel and its usage also increased. From figure 1, the renewable energy is the sixth largest fuel but since 2010, it is strong growth pushed up and it tend to increase every year.

Energy usage in Thailand is still dependent on fossil fuels as the main energy while the renewable energy resource is still second choice. It tends to grow in the future, especially in agricultural residues which has potentials for energy conversion. The important by-product of an agriculture-based country apart from the agricultural products, is the agricultural residues such as rice straw, rice husk, bagasse, and palm empty bunches etc. Most agricultural residues were burnt without any benefit so the method for converting biomass to fuel was a good choice for replacing fossil fuel. The advantages of biomass fuel are increasing stability in the country's energy production because amount of biomass is sufficient to be used as renewable energy.



**Fig. 1 - Shares of global energy consumption by resources since 1885 to 2018 [1]**

The process for converting agricultural residues to heat can be divided into 3 processes [3]: (1) Thermochemical conversion processes such as pyrolysis, direct combustion, gasification; (2) biochemical conversion processes such as fermentation, anaerobic digestion; and (3) biotechnology and nanotechnology-based process. The implementation depends on the type of product of the process [4] such as solid fuel, example char, carbon etc., liquid fuel, example biodiesel, tar, bio oil etc., and gas fuel, example biogas, synthetic gas, smoke etc. The agriculture residues used in this work are available in Thailand. It can be divided to 3 shapes which are: (1) chip shapes were wood chips and coconut shell, (2) fiber shapes were oil palm empty fruit bunches and corn straw, and (3) powder shapes were sawdust and mixed palm cake.

The most easily energy converter process of three shapes is direct combustion. The direct combustion is the first choice for converting agricultural waste to hot gases or steam for energy [5] in a combustion chamber. For advantages of this process can combust many types of fuels having non-uniform size and can be practically operated. From literature, it found that the work used to convert agricultural waste into heat energy as follows; (1) study on combustion of the same types of biomass with different shapes [6-7], (2) study on combustion of different types of biomass with the same shapes [8-9], and (3) study on combustion of different types of biomass and different shapes [10-11]. Conversely, it cannot find work studies about combustion on the different types and different shapes of biomasses using the same combustion chamber with varying air velocity.

For method of analyze direct combustion of biomass in literature can be divided into 2 parts. 1st part, the temperature at each position along combustion chamber was studied. It is important part to indicate the quality of combustion, and they were an indicator of the combustion boundary zone within the reactor [12-13]. For 2nd part, the flue gas was analyzed, but the flue gas has high temperature and more dust. It wasn't suitable to direct measure, so it must be clean up and reduce temperature before analyzing [14]. Carbon monoxide is one of the most important variables in indicating efficiency of combustion or used to describe the suitability of air and fuel [13, 15].

The aims of this work were to study burning biomass by using combustion chamber with different types of 6 biomasses (Categorizing by 3 shapes). The mass of biomass was fixed while the air velocity was varied.

## 2. Methods

### 2.1 Biomass

Biomasses used in this work were from agriculture residue which are available in southern region in Thailand. It consists of 6 types of fuels grouping into 3 shapes. (1) Chip shapes were rubber wood chips (figure 2(a)), and coconut shell (figure 2(b)). The size of chip shapes was approximately 30 mm x 30 mm x 50 mm. (2) Fiber shapes consists of

oil palm empty fruit bunches (figure 2(c)), and corn straw (figure 2(d)), and (3) powder shapes were rubber wood sawdust (figure 2(e)) and mixed palm cake (figure 2(f)) which is extraction from mixed crude palm oil (Combined palm kernel and mesocarp). The size of powder shape was in the range of 1-10 mm.



**Fig. 2 - Biomasses used in the present work**

Table 1 shows the physical and chemical properties of biomass samples from literatures, which were available in southern region of Thailand. The moisture content of biomasses used in this work were lower than 20%. It can be noted that the carbon content of rubber wood chips and sawdust in Table 1 were almost same because of they were same biomass of rubber wood. However, the moisture content of sawdust was higher than rubber wood chips. The mixed palm cake had the highest amount of carbon content, which may lead to higher combustion temperature.

**Table 1 - The properties of biomass from southern region of Thailand**

Parameter	Unit	Chip shapes		Fiber shapes		Powder shapes	
		Rubber Wood chips [16]	Coconut Shell [17]	Empty fruit bunch [18]	Corn Straw [19]	Sawdust [20]	Mixed palm cake [21]
<b>Ultimate analysis</b>							
Carbon: C	% wt..	46.39	45.25	40.70	44.53	46.40	47.01
Hydrogen: H	% wt..	5.75	5.00	5.40	5.88	7.10	6.20
Nitrogen: N	% wt..	0.02	0.83	0.30	0.17	0.12	1.17
Oxygen: O	% wt..	14.71	20.34	47.80	42.16	44.80	39.18
Sulphur: S	% wt..	0.00	0.03	1.20	0.05	0.03	0.16
<b>Proximate analysis</b>							
Moisture content	% wt..	8.50	12.56	n/a	6.12	17.00	6.12
Fixed carbon	% wt..	14.75	18.63	27.90	19.45	15.60	17.67
Volatile	% wt..	83.09	62.96	67.50	73.35	65.90	70.61
Ash	% wt..	0.83	5.89	4.60	7.20	1.50	5.60

## 2.2 Experiment Setup

The schematic diagram of the experimental setup is shown in figure 3. The combustion chamber was a simple updraft type. The diameter of combustion chamber is 20 cm, and the total height of the combustion chamber from the bottom end to the tip is 160 cm. 1-kg biomass was fed into the chamber and fall on the grate at the bottom of combustion chamber. After that it was burnt with air. The blower sucks air from environment passing to the combustion chamber at the height of 15 cm. The air flowed into the combustion chamber with 2 ways. The air flow rate was controlled with varied velocity. In the part of ashes, it was heaped below the bottom of combustion chamber and was removed to ash storage box after combustion.

The flue gas flow up to the top of combustion chamber and passing to 1<sup>st</sup> cyclone for separating flue gas from dust and the 2<sup>nd</sup> cyclone for filtering smaller dust before leaving to environment. The dust and small particle of each cyclone falls to ash storage box.

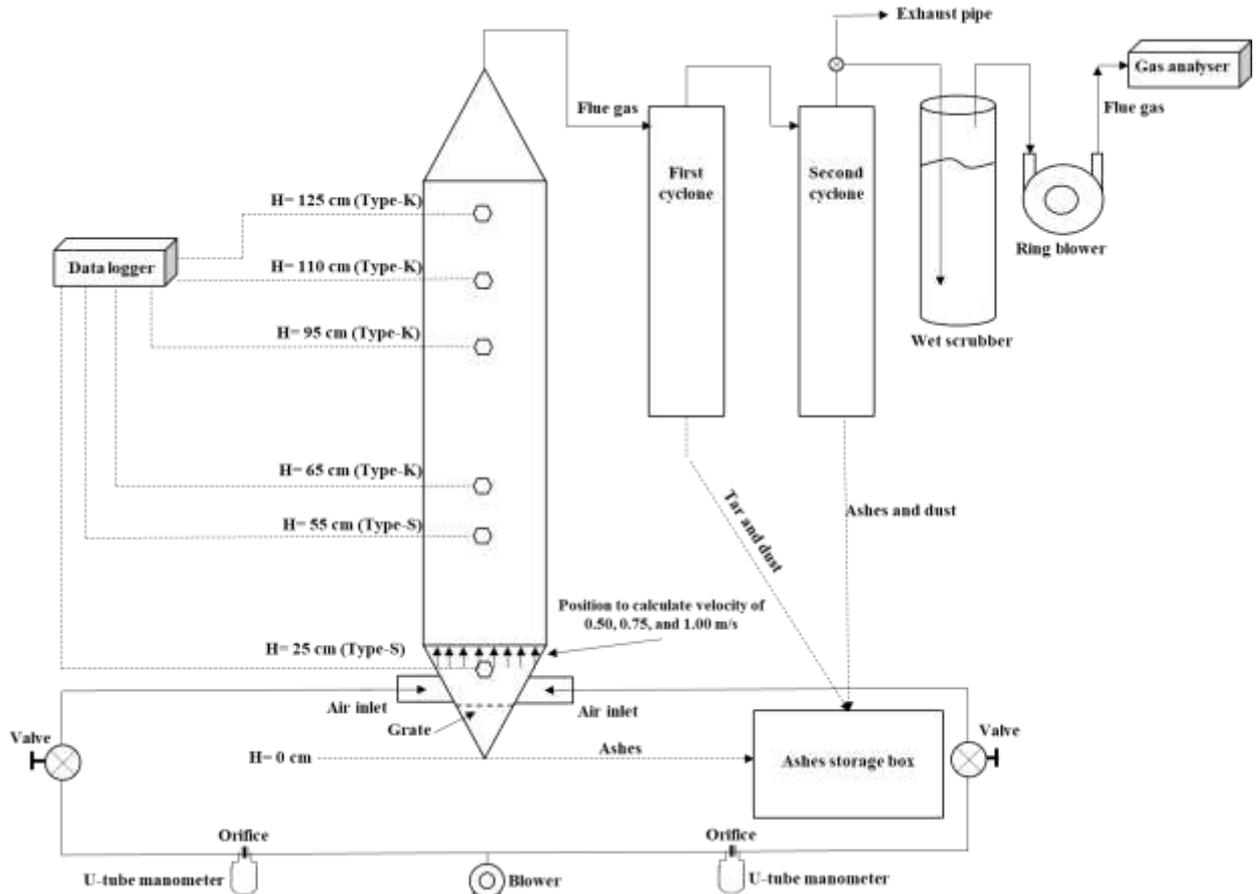


Fig. 3 - Schematic diagram of the updraft combustion chamber

Table 2 - Details of the instruments

Parameter	Device	Accuracy
Temperature	- Data logger: Hioki LR8400-20, Japan	± 0.1 °C
	- Thermocouple S type Primus Tss-14 15x200+50-B, Thailand	-300 – 1700 °C ±2.2°C
	- Thermocouple K type Primus Tsk-14 15x200+50-B, Thailand	-100 – 1350 °C ±0.8°C
Gas analyzer	Flue gas analyser: Testo 300, (O <sub>2</sub> , CO, H <sub>2</sub> ), Germany	CO measurement ±20 ppm (0 to 400 ppm) ±5% of m.v. (401-2,000 ppm) ±10% of m.v. (2001-4,000 ppm)

### 2.3 Temperature and Flue Gas Measurement

Type-S and Type-K thermocouples were located along the center of the combustion chamber height to measure combustion temperature. Figure 3 shows the 6 measured positions of the combustion chamber which consists of 2 positions of Type-S thermocouples. They were installed at the burning zone of chamber because that positions have high temperatures. For 4 position of Type-K thermocouples were installed at the upper combustion chamber (H= 65, 95, 110, 125 cm.). In order to reduce heat loss, the combustion chamber was insulated using high temperature insulator (KAOWOOL, ASK-7912-H 8P Blanket 1,400°C).

In beginning, the ignition lid was opened. Then, 0.1 kg of biomass was feeding in the updraft combustion chamber for direct burning, using gasoline. During internal biomass burning, the 0.9 kg of biomass was added into the combustion chamber. The temperature in the level of combustion chamber (6 positions) were recorded one time per

minute in the datalogger. The flue gas was cleaned using water scrubber as shown in figure 3. Carbon monoxide of flue gas (CO-which is the quantity indicating the combustion quality of the fuel gas) was measured by using gas analyzer. The instruments for measuring the temperatures and the carbon monoxide in flue gas are shown in Table 3.

## 2.4 Experimental Parameters

The mass of biomass sample was fixed at 1 kg/experiment and the mass flow rate of air was varied corresponding to a velocity of  $v=0.50$ ,  $0.75$  and  $1.00$  m/s which was calculated at  $H= 25$  cm (at the same position of the first thermocouple) as shows in figure 3. The blower accelerated the air which flow through the calibrated orifice flow meter with u-tube manometer. The flow rate of air was controlled by adjusting the blower speed with an inverter. Noted that air velocity which was calculated at each inlet pipe were 2, 3, 4 m/s, corresponding to  $v = 0.50$ ,  $0.75$ ,  $1.00$  m/s at the combustor inlet, respectively. For higher velocity would cause some types of biomass as sawdust to spread away.

Table 3. shows the stoichiometry of each samples to burn a kilogram of biomass and their respective equivalent ratio (ER) with varying velocity of air [22]. It was found that the average of equivalence ratio for each velocity can be expressed as  $ER_{Ave @ v=0.50m/s} = 1.38$ ,  $ER_{Ave @ v=0.75m/s} = 1.77$  and  $ER_{Ave @ v=1.00m/s} = 2.45$ . All 6 types of biomass and the required air for complete combustion were arranged as follows: fiber shapes, powder shapes, and chip shapes.

**Table 3 - Details of air fuel ratio (A/F ratio) and equivalence ratio (ER) for varying air velocity**

Parameter	Chips shapes		Fiber shapes		Powder shapes	
	Rubber Wood Chips	Coconut Shell	Empty fruit bunch	Corn Straw	Sawdust	Mixed palm cake
<b>Air fuel ratio (A/F ratio) of theory for complete combustion</b>						
A/F ratio ( $kg_{air}/kg_{fuel}$ )	5.33	8.47	4.70	5.75	5.95	6.25
<b>Equivalence ratio (ER) on varied air velocity</b>						
$V = 0.50$ m/s ( $0.0084$ m <sup>3</sup> /s)	1.80	0.66	0.97	1.76	1.45	1.62
$V = 0.75$ m/s ( $0.0126$ m <sup>3</sup> /s)	2.13	1.07	1.00	1.85	1.79	2.79
$V = 1.00$ m/s ( $0.0169$ m <sup>3</sup> /s)	2.66	1.31	1.08	3.34	3.32	3.07

## 3. Results and Discussion

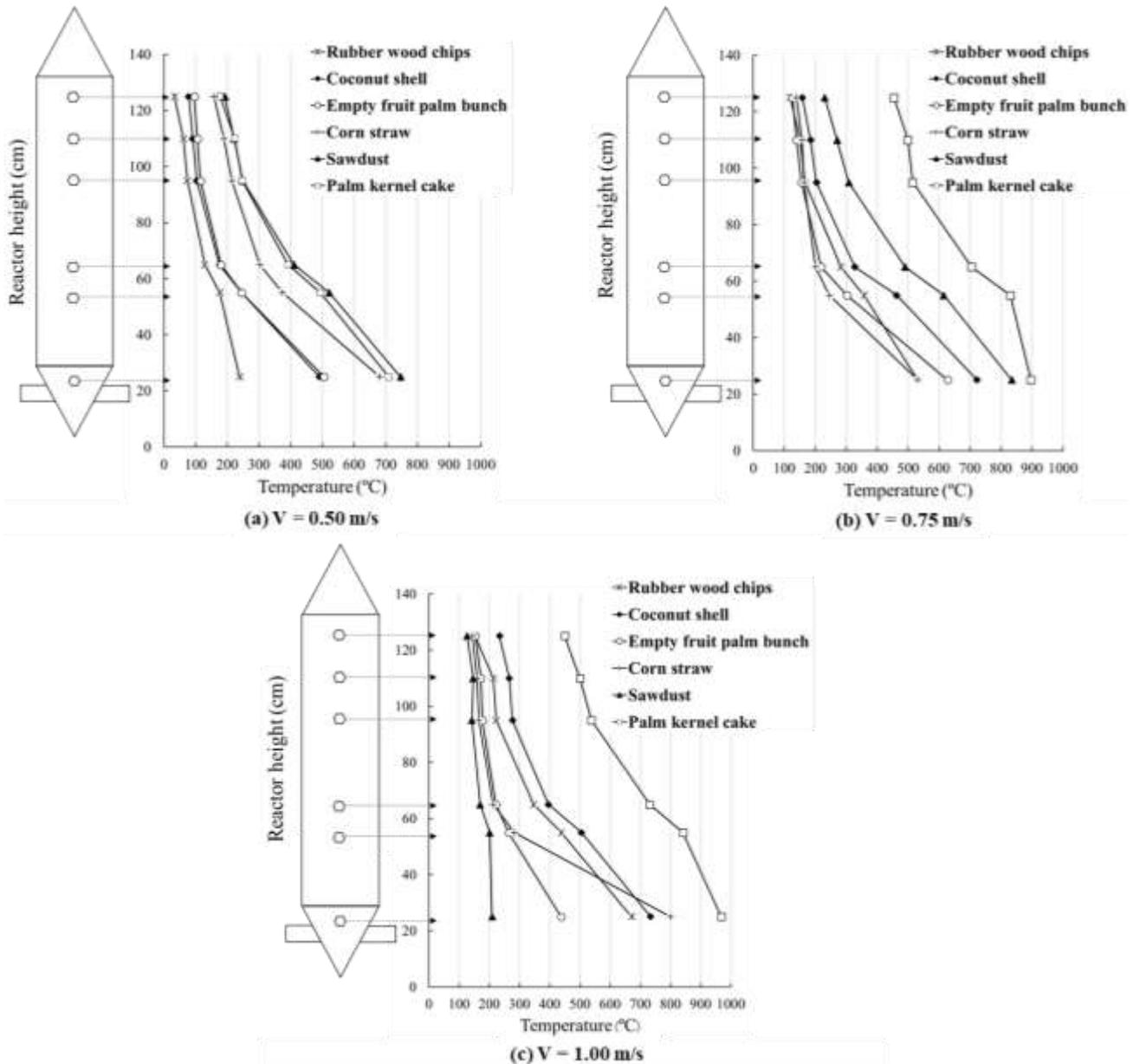
### 3.1 The Temperature Profiles Along Combustion Chamber Height

Temperature profiles of biomass combustion along chamber height at  $H=25$ ,  $55$ ,  $65$ ,  $95$ ,  $110$ ,  $125$  cm were shown in figure 4. It was found that the temperature inside the combustion chamber decreased when the position was higher. The temperature profile can be divided into 2 groups: (1) The bottom of combustion chamber ( $H = 25$ ,  $55$ , and  $65$  cm) provided high temperature profiles particularly at  $H = 25$  cm indicating combustion zone. In this group, the temperature profiles of each biomass were different, clearly seen. (2) The top of combustion chamber ( $H = 95$ ,  $110$ , and  $125$  cm), the combustion temperature profiles were low and it had almost similar temperature range except for mixed palm cake in which the temperature profiles at  $v = 0.75$  and  $1$  m/s were higher than that of other biomasses.

At  $V = 0.50$  m/s as shown in figure 4(a), the maximum temperature occurred at  $H = 25$  cm because it was the first position that the biomass interacted the air. For the biomass that provides the high temperature profile can be arranged in the following order: sawdust, mixed palm cake, corn straw, oil palm empty fruit bunch, coconut shell, and wood chips. Considering high temperature from the effect of shape characteristic was powder biomass.

At  $V = 0.75$  m/s as shown figure 4(b), the mixed palm cake had maximum temperature. For other types of biomass can be arranged in the following order: sawdust, coconut shell, oil palm empty fruit bunch, wood chips, corn straw. In addition, the first two of maximum temperature were mixed palm cake and sawdust, respectively. It clearly shows that if velocity increased (From  $V = 0.50$  m/s to  $V = 1.00$  m/s), the powder shapes were burnt better than other cases.

In the case of  $V = 1$  m/s as shown in figure 4(c), chip shapes such as rubber wood and coconut shell had higher temperature in combustion chamber than other condition because the air velocity increased. For mixed palm cake and corn straw have high temperature at  $H = 25$  cm. However, when the chamber was higher, the combustion temperature of mixed palm cake was still high indicating wider combustion zone, but the one of corn straw was immediately reduced.



**Fig. 4 - Variations of temperature along the center of combustion chamber**

Considering the mixed palm cake in figure 4, it can be noticed that it provided maximum temperature, especially at  $V = 0.75 \text{ m/s}$  and  $1.00 \text{ m/s}$ . In addition, considering at  $H = 55 \text{ cm}$ , the temperature of mixed palm cake was higher than that of other biomasses. It can reason that wider combustion zone from floating with burning of mixed palm cake when air velocity increased. However, it is different with sawdust case (Powder shapes) that the combustion temperature was high at  $V = 0.50 \text{ m/s}$  and  $0.75 \text{ m/s}$ , but it was the lowest at  $V = 1 \text{ m/s}$  due to floating without burning as a result of very high inlet air velocity. The different combustion characteristics at high velocity,  $V = 1 \text{ m/s}$ , is from that the bulk density of mixed palm cake is larger 3 times that of sawdust [23, 24]. This can be explained that the mixed palm cake was floating with burning due to larger bulk density while the sawdust was floating away without burning due to smaller bulk density.

The result shows that the powder shapes of biomass, which are mixed palm cake and sawdust, are more advantageous in term conversion to heat rate for updraft chamber. The finding is in similar to that of Agata .et .al [25] and Gianluca et.al. [26].

### 3.2 Carbon Monoxide Volume in Flue gases

Carbon monoxide content (ppm) in flue gas which was measured by using flue gas analyzer (Testo 300) is shown in figure 5. The cyclone and wet scrubber were used to clean the flue gas by filtering ashes, tar, and dust before measuring. The results of this study can be sorted in order to release carbon monoxide content from minimum to to

maximum by the following: wood chips, coconut shell, palm oil empty fruit bunch, mixed palm cake, sawdust, and corn straw. According to the flue gas quality of industrial emission standards of fuel combustion carbon monoxide [27, 28], must be less than 690 ppm as indicated by dash line in figure 5. Furthermore, carbon monoxide volume of flue gas can be divided into 3 group:

- 1) Chip shapes: In this group, flue gas quality was the best but low combustion temperature. The effect of air velocity of this group slightly affects the decreasing of carbon monoxide while the effect of biomass shape can reduce carbon monoxide which was lower than other biomasses as clearly seen in figure 5. In addition, the carbon monoxide of flue gas was lower than industrial standard as recommended by [27, 28].
- 2) Fiber shape: an increase in air velocity did not affect the reducing carbon monoxide. For burning biomass in this group was very complicated especially at  $V = 0.75$  m/s (Medium air velocity), because it makes high carbon monoxide for all fiber shapes as indicating curve line in figure 5. For the extreme case was corn straw which has very high carbon monoxide throughout air velocity. It should be concerned for environmental impact for practical burning of this biomass type.
- 3) Powder shape: an increase in air velocity caused to reduce carbon monoxide monotonically as indicated by inclined line as shown in figure 5. Thus, it shows that in this group can control carbon monoxide volume to be lower by adjusting flow rate of supplying air.

In short, for the case of carbon monoxide being lower than 690 ppm as recommended by [27, 28] were rubber wood chips, coconut shell, and mixed palm cake at air velocity 1 m/s. From this study, the optimal condition of biomass combustion by getting low carbon monoxide and high combustion temperature is mixed palm cake at  $V = 1$  m/s.

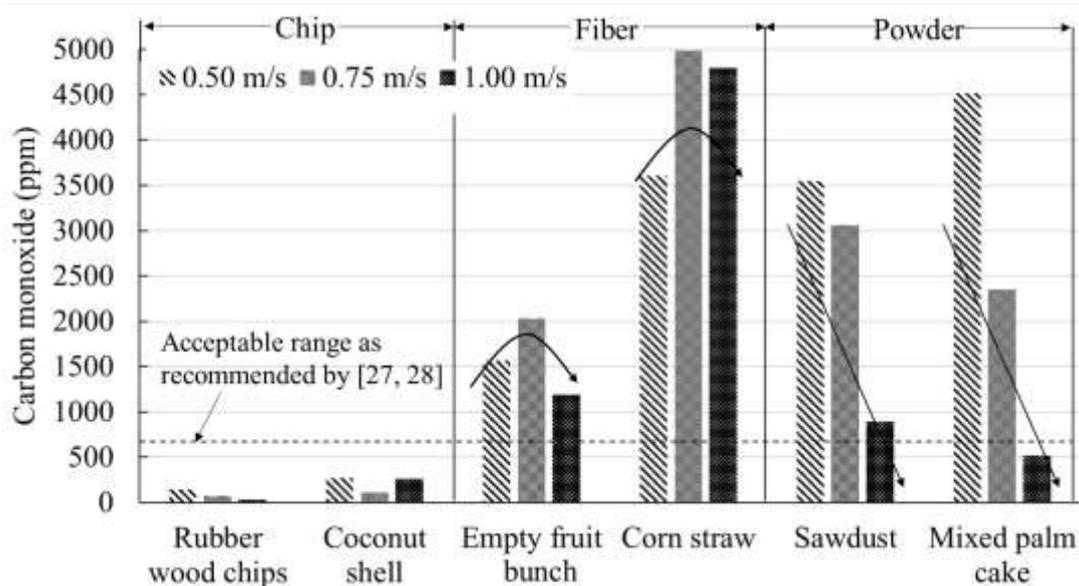


Fig. 5 - Carbon monoxide in flue gases

#### 4. Conclusion

In this study, biomass samples including, rubber wood chips, coconut shell, oil palm empty fruit bunches, corn straw, rubber wood sawdust, and mixed palm cake were combusted using simple cylindrical combustion chamber at different air velocities. Based on the obtained result, it can be summarized below:

- 1) Combustion of chip biomass at low air velocity (at  $V = 0.50$  m/s) was difficult to combust. An increase in air velocity helped to improve the combustion temperature. Carbon monoxide content (ppm) from this biomass combustion was lowest in all cases.
- 2) Combustion temperature obtained from combustion of fiber shape biomass was low as compared to other biomasses. The emission of carbon monoxide (ppm) was also in the high range, especially the corn straw which was the highest.
- 3) Combustion of powder shape biomass led to high temperature during burning as compared to other biomasses. However, with this biomass an increase in air velocity is risk to occur the problem of unburned biomass due to some powder biomass was carried from combustion chamber before burning completely.

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