Development of Portable Venturi Kiln For Agricultural Waste Utilization By Carbonization Process

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Abstract: Many types of kiln or carbonization equipment have been developed, but most of them were designed for big capacity and some also having low performance. This research aims to develop kiln, especially portable metal kiln, which has higher performance, more environmental-friendly, and can be used for several kinds of biomass or agricultural waste (not exclusive for one kind of biomass) as feeding material. To improve the kiln performance, a venturi drum type of portable kiln has been designed with an optimum capacity of 12.45 kg coconut shells. Basic idea of those design is heat flow improvement causing by venturi effect. The performance test for coconut shell carbonization shows that the carbonization process takes about 60-90 minutes to produce average yields of 23.8%., and the highest temperature of the process was 441 ^{o}C. The optimum performance has been achieved in the 4th test, which was producing 24% yield of highest charcoal quality (represented by LHV) in 65 minutes process at average temperature level 485 ^{o}C. For pecan shell and palm shell, design modification has been done by adding 6 air inlet holes and 3 ignition column to get better performance. While operation procedure should be modified on loading and air supply, depending on each biomass characteristic. The result of performance test showed that carbonization process of pecan shell produce 17 % yield, and palm shell produce 15% yield. Based on Indonesian Standard (SNI), all charcoal produced in those carbonization has good quality level.

1. Introduction

Some of biomass waste has been utilized for many purposes such as handicraft and accessories raw materials, active carbon, and also as charcoal for cooking and heating process. But huge of them still have not been utilized well and potential to causing an environmental problem. Carbonization, a thermal decomposition process based on the pyrolysis, is one of the best utilization, especially for woody biomass waste, since it produces economic products. Many types of carbonization equipment have been developed, but most of them were designed for big capacity or has low performance.

Lacross (1985) in [1] explain that high yield of carbonization will be achieved if the pyrolysis process occurred on the primary pyrolysis steps at a temperature range of 150-350 ^{o}C, but high temperature will produce higher carbon quality. Implementing venturi effect in the kiln design should be producing higher velocity and temperature of the gas flow inside the kiln or carbonization chamber. Thus carbonization condition will be better and more efficient.

Many designs of kiln have been developed since several years ago. Regular drum type has been chosen since it's easy to build by using regular 'used oil drum' as its main structure, which can be found easily in the rural or urban area [2]. This study aims to develop portable venturi kiln to improve

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the portable drum kiln performance by implementing venturi effect in the pyrolysis or carbonization chamber.

To increase performance, the kiln should be designed or operated based on each feeding material characteristic. Since biomass or agricultural waste varies in the very wide range, not only in its physical properties but also its composition, some modifications should be done both in kiln design process and in the kiln operation to get optimum performance of the kiln.

2. Method

In general, the kiln development stages are starting with design approach, continuing with design process and construction, then following with performance test and data analysis, and finishing with a recommendation for performance improvement as shown in the flowchart below.

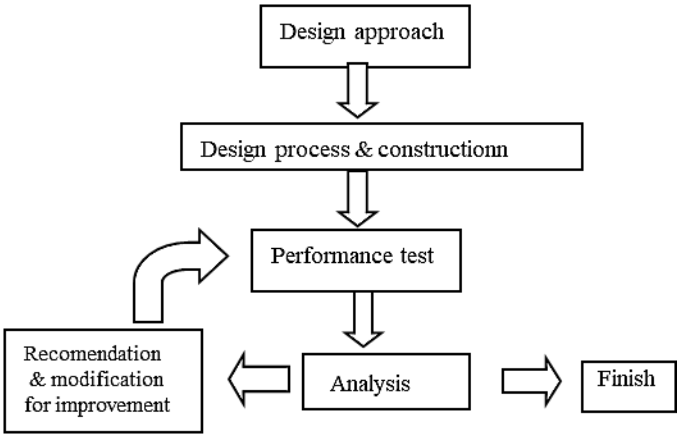

Figure 1. Stages of research activities.

As result of the design approach, kiln was designed as venturi drum type which consists of 6 (six) parts or sections as shown in figure 2. The parts were called as combustion section (d), carbonization section or pyrolysis chamber (f), heating column (c), chimney (a), kiln cover (b), and kiln support (e) as shown in figure 2. The total kiln height is 1763 cm and the wide is 572 cm. Volume (capacity) of carbonization chamber or pyrolysis chamber (f) is 0.3 m^3 or about 13 kg of coconut shell with 2/3 volume occupation, so there is enough space for heat gases which will be produced while pyrolysis process occurred. Combustion section in the bottom part of kiln (d) was designed for initial heat energy supply for the carbonization process, as same as the function of heating column in the upper part of the kiln (c).

Performance of the kiln was evaluated based on several parameters; they were: optimum capacity (kg coconut shell as feedstock), temperature of the process, time or duration of the process, yield and quality of the product. 2 (two) pre-testing was conducted to get the optimum condition of the kiln operation which produced best yield and quality. Main testing was done for 5 carbonization processes. Coconut fiber and coconut shell have been used for initial heat energy supply which was burned (combusted) in the heating column and the combustion section. After performance test by using coconut shell as feedstock, performance test was carried out by using palm shells and pecan shells as feed-stock material. For pecan shell and palm shell, the procedure were same, but some modification has been applied to get the best kiln performance.

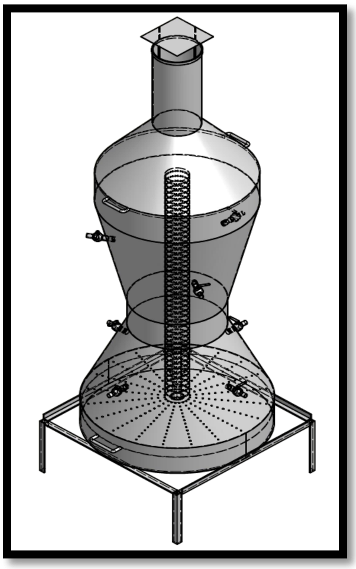

Figure 2. Structure of portable venturi drum kiln

Figure 3. Palm shell

Figure 4. Pecan shell

3. Result and Discussion

Portable venturi drum kiln which has been designed is presented in figure 5 below, and the performance test condition presented in figure 6.

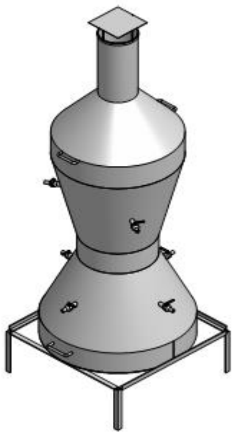

Figure 5. The kiln

Figure 6. Performance test

3.1. *Kiln capacity*

Pre-testing shows that optimum capacity of the kiln, means the total weight of coconut shell which occupied 75% carbonization chamber, is about 12 - 13 kg, depending on the coconut shell size. The test also shows that the shape and dimension of coconut shell as feedstock, influence the time or duration of the process and also the temperature of carbonization process, those influences the yield. Coconut shell with big size and half sphere shape, producing higher yield (with the same quality) compare to the smaller size, due to its higher temperature and longer process (table 1). But, in the real condition, coconut shell found in the municipal waste was not uniform in size and shape, but mostly in small size**.** So, most of the performance test was done by using small size coconut shell as feeding material.

Performance test by using pecan shell and palm shell, which has better uniform shape and size but smaller than coconut shell, shows that capacity of the kiln was about 34 kg for pecan shell and about 31 kg for palm shell. Higher density of pecan shell and palm shell (compare to coconut shell) causing lower kiln performance (Tabel 2) due to the smaller porous among the shell. Thus, modification should be taken on the pyrolysis chamber to get better performance. Two air column addition has been successful in improving carbonization process but reducing kiln capacity as result of the chamber volume reduction. The kiln capacity became 30-31 kg for pecan shell and about 28 kg for palm shell.

3.2. *Kiln performance for coconut shell carbonization*

Kiln performance for coconut shell carbonization presented as data shown in Tabel 1 and figure 7, figure 8 and figure 9. Based on data in figure 7 and table 1, higher temperature in the 3rd, 4th and 5th test, compared with the 1st and 2nd test, were producing less yield (less amount of charcoal). Those result was matching with pyrolysis theory, which was defined that higher temperature in carbonization process will produce less yield. But this condition (higher temperature) producing better charcoal quality, representing by LHV (Lower Heating Value), as shown in figure 9. Those result also matched with the theory which defined that higher temperature of the process will produce charcoal with higher carbon content so that the charcoal will have higher energy (LHV) content.

Table 1 also shows that big size coconut shell produced higher yield compared with small size. It produced shorter temperature range as shown in figure 7, due to air column among the material layer. While kiln operation by using small size coconut shell shows that best yield achieved in the 1st test. Those process running at average temperature of 270 ^{o}C and highest temperature of 552 ^{o}C, producing 26% yield and all of coconut shell was 100% successfully pyrolyzed.

Table 1. Kiln performance by using coconut shell as feed stock

Test no	Coconut shell (kg)	MC (%)	Coc.shell size	Process time (minute)	Average temp. (^{o}C)	Highest temp. ^{o}C)	Yield (%)	Quality
1	12.45	12.64	Small	65	270	552	26	G
2	12.45	13.03	Big	90	386	541	27	G
3	12.45	12.84	Small	65	554	989	22	G
4	12.45	13.41	Small	70	485	908	24	G
5	12.45	13.41	small	60	558	977	20	G

Note: G= good quality

3.3. *Venturi effect on the carbonization process*

Temperature level during carbonization proses which was presented in figure 7, and temperature distribution inside the kiln (figure 8), were influenced by venturi effect of the throat inside carbonization chamber. Those data showed that venturi throat had successfully reduced the differences temperature between middle and upper level of the kiln as shown in the 1st, 4th and 5th tests. Thus the process temperature could keep in almost same level due to the speed of gas velocity through the venturi tube. In the 2nd and 3rd tests, the venturi effect failed to keep the temperature. It could happen when the throat was interrupted (by material), but it could not recognize or investigate in this study due to the kiln wall was not transparent [2].

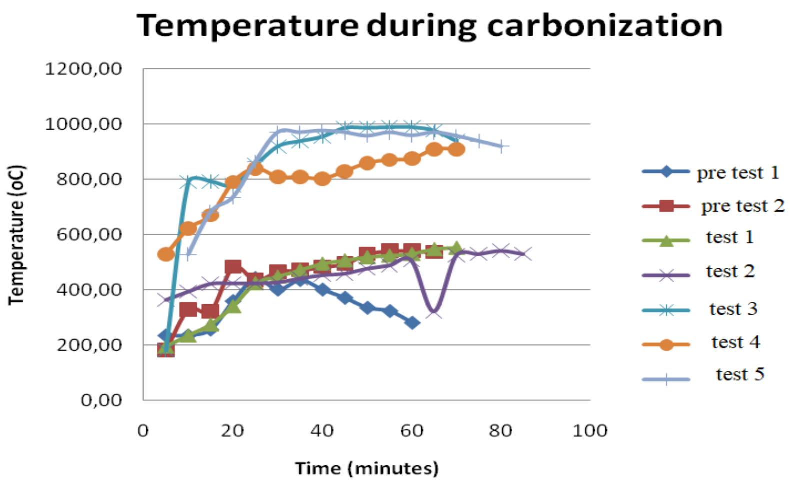

Figure 7. Temperature level during coconut shell carbonization

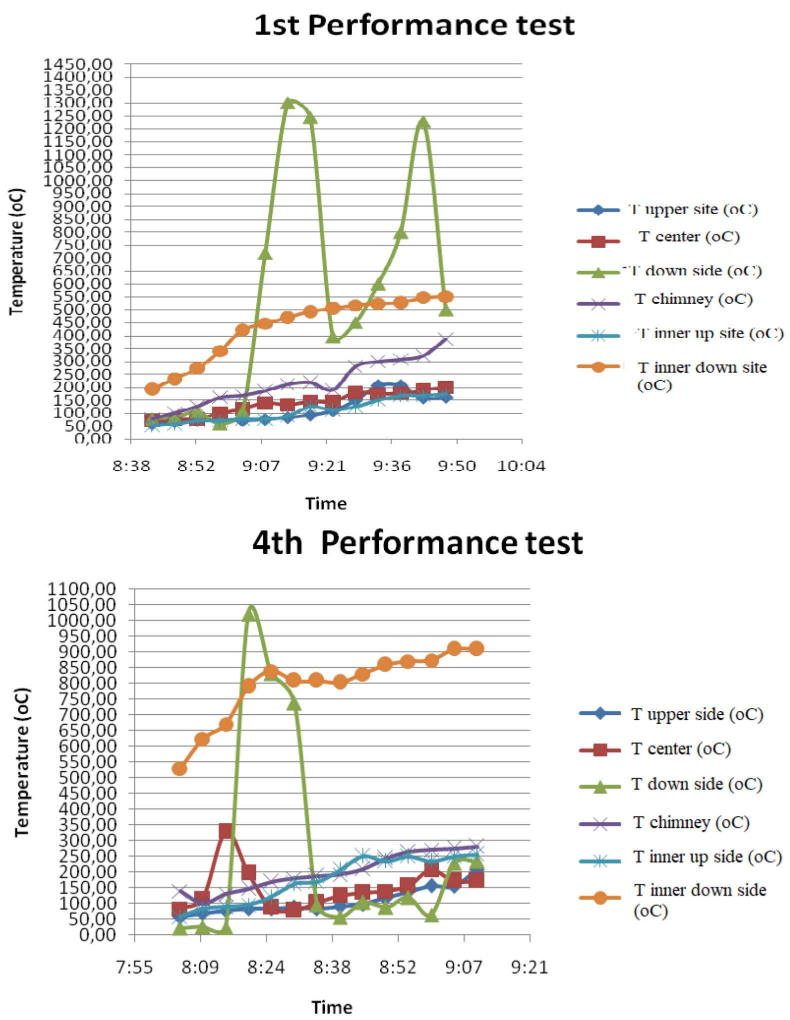

Figure 8. Temperature distribution inside kiln chamber

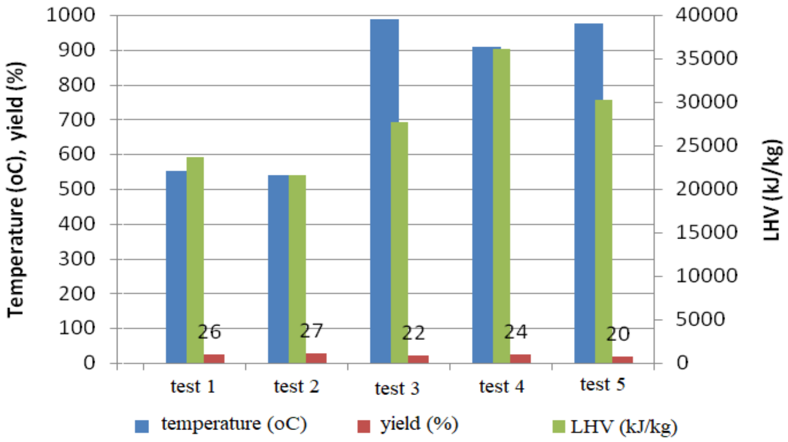

Figure 9. Relationship of temperature, yield, and charcoal quality

Figure 10. (a) Coconut shell charcoal, (b) charcoal inside, representing the quality

3.4. *Kiln performance for pecan shell and palm shell.*

Result of performance test of the kiln by using pecan shell and palm shell as feeding material presented in table 2, figure 11 and figure 12 below.

Tabel 2. Kiln performance for pecan shell and palm shell

No	Parameter	Palm shell	Pecan shell
1	Optimum capacity (kg)	31.35	34.17
2	Bulk density (kg/m3)	88.57	128.00
3	Carbonization time (minutes)	313.5	346.5
4	Process time (minutes)	362.5	396.25
5	Average carbonization temp (oC)	239.22	226.92
6	Highest temperature (oC)	433	378
7	Yield (%)	15.32	17.07
8	Un-pyrolized raw material (kg)	17.97	16.40

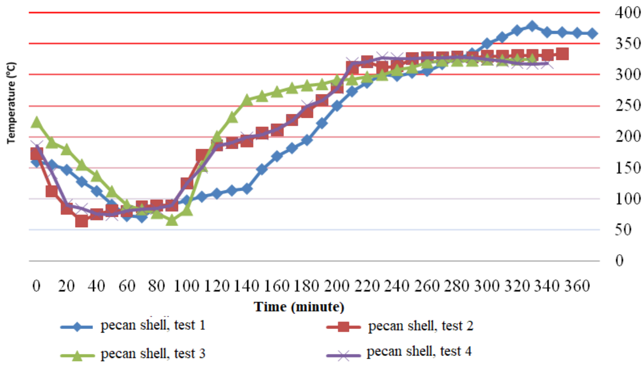

Figure 11. Temperature pattern in pecan shell carbonization

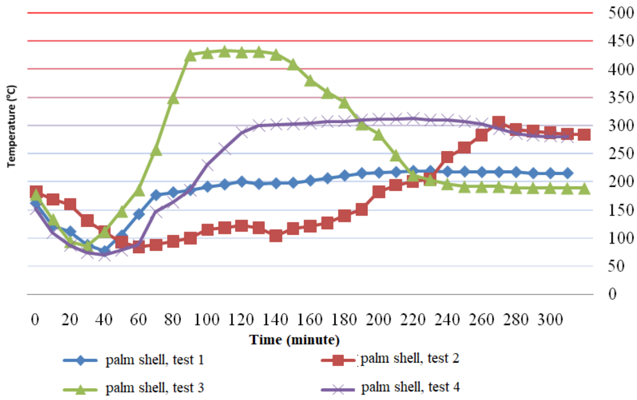

Figure 12. Temperature pattern in palm shell carbonization

The data shows that the kiln performance for pecan shell and palm shell carbonization was poor than its performance for coconut shell. Some modification has been made to improve the kiln performance as shown in table 3. Modification of operation procedure also applied to material feeding/loading. For coconut shell, all material can be loaded to the carbonization chamber as much as kiln capacity, but for pecan shell and palm shell loading should be done step by step to give enough time for material to be pyrolyzed.

Table 3. Kiln modification

No	Component	Original design	Modification
1	Air inlet holes:		
	a.number of holes	7	13
	b.size (inch)	0.75	0.75
	c. position	Center & bottom	Center & bottom
2	Air distribution column	1	3

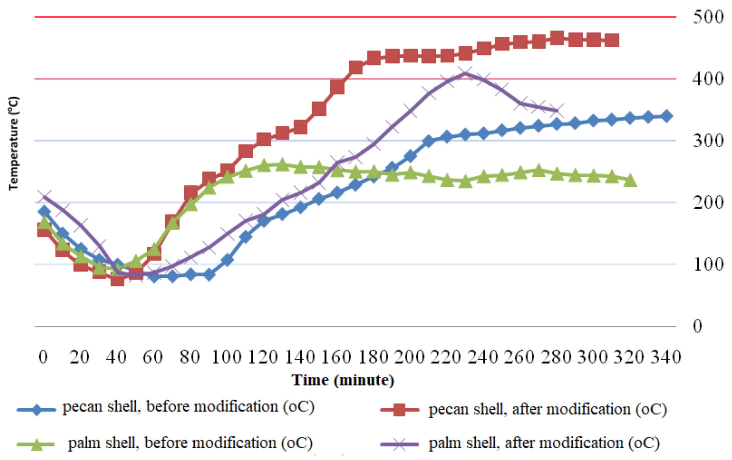

Figure 13. Temperature of pecan shell and palm shell carbonization, before and after modification

Result of the modification presented in table 4 and figure 13. The data shows that modification successfully on improving kiln performance, which is representing by decreasing of carbonization time and un-pyrolyzed material, and increasing carbonization temperature and charcoal yield. But, the kiln capacity was lower due to the space reduction as result of additional "air distribution column".

Table 4. Result of kiln performance test for pecan shell and palm shell, before and after modification

Parameter	Palm shell (original design)	Palm shell (modified)	Pecan shell (original design)	Pecan shell (modification)
Optimum capacity (kg)	31.35	28.03	34.17	30.93
Total carbonization time (minutes)	362.50	333	396.25	360
Temp. of carbonization (°C)	239.2	240.7	226.9	321.
Yield (%)	16.43	26.65	17.07	23.21
Un-pyrolized material (kg)	17.19	0.0	16.40	8.52

4. Conclusion

The venturi drum kiln which has been designed based on the coconut shell characteristic, having total size of 1763 cm height and 572 cm width, and (volume) capacity about 0.3 m3 or about 13 kg coconut shell. The performance test shows that optimum capacity of the kiln is 12.45 kg of coconut shell, and the best yield achieved by the 1st test, which was running in average temperature 270 °C and highest temperature 552 °C , producing 26% yield, and the material was 100% pyrolyzed. Best charcoal quality achieved by the 4th test, which was running in average temperature 485 °C, highest temperature 908°C, and produce 24% yield.

Venturi throat has successfully reduced the differences of temperature between middle and upper level of the kiln as shown in the 1st, 4th and 5th tests. Thus the process temperature could keep in almost same level due to the speed of gas velocity through the venturi tube.

For pecan shell and palm shell carbonization, the kiln has poor performance and some modification should be taken to improve the performance. Modification on air inlet system and material loading has been successful in improving kiln performance, but causing reduction of kiln capacity from about 34 kg to 30 kg of pecan shell, and from about 31 kg to 28 kg of palm shell. The yield was increasing from 17% to 23% for pecan shell, and from 16.43% to 26.6% for palm shell. Even though the modification achieving better carbonization result for palm shell than pecan shell, but design improvement of this venturi kiln still needed to get higher performance, and also availability for other biomass.

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