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Research Article

Design and performance evaluation of a Pyrolysis Reactor for vegetable biomass conversion to usable energy

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Abstract

This paper deals with the design of equipment for conversion of vegetable biomass wastes to usable energy. The procedures employed include the design stage, the construction stage and the testing one. After metallic construction, the pyrolysis reactor was insulated by firebrick to minimize heat losses and protect operators. The equipment designed was tested with Cashew nut shell, coconut shell, palm nuts hull, rice hull shell and cassava peel. The tests have shown that the five biomasses used are convertible into gas (84.61%, 98.67%, 72.31%, 73.08% and 78.47% respectively for Cashew shell, Coconut shell, Palm nuts hull, Rice hull shell and Cassava peel and coal (15.38%, 1.33%, 27.69%, 0% et 11% respectively for Cashew shell, Coconut shell, Palm nuts hull, Rice hull shell and Cassava peel). The Released energies are 156 MJ for Cashew shell, 135.72% for Coconut shell, 113.75% for Palm nuts hull, 89.7% for Rice hull shell and 117% for Cassava peel. The highest flame temperature was recorded as 763°C when Cashew nut shell was used.

Keywords: *Design, Pyrolysis reactor, Vegetable Biomass, Energy recovery, Benin*

1. Introduction

Energy is an important input in all sectors of any country's economy. There is a great deal of interest today about the development and increased production of energy needs from alternative energy sources. Biomass is widely considered as an important potential fuel and renewable energy resources for the future(Panwar 2009). Unfortunately, in Benin, the use of biomass as an energy source is not common. Faced to the difficulties in energy access and management of waste from the processing of cashew nuts, in collaboration with CEFREPADE and Rongead, the University Institute of Technology of Lokossa carried out an experiment of cashew nut shell processing into gas and coal(Godjo *et al*;. 2015). This experiment resulted in the implementation in Benin of three pyrolysis plants. Those pyrolysis plants have been used for energy recovery from cashew nut shells. The experiment of promotion of cashew nuts showed that the pyrolysis reactor used can be able to produce gas energy of approximately 82% of the hull mass processed and produces about 18% of charcoal. Furthermore, on the energy point of view, the recovered gas corresponds to 74% of the energy of the raw material, while the obtained charcoal (18% of raw material) corresponds to 26% of total energy of raw material.

However, the installed pyrolysis reactors have great capabilities. The diameter of central cylindrical core heater is 1,350 mm, the height of central cylindrical core heater 1,350 mm, the power rating is 118 kW and the released energy is 1,837MJ (Godjo *et al*. 2015).

Although this technology is effective and efficient for industrial processing units, its performance is too high for small industrial units. Indeed, Benin industrial sector is mainly composed of small scale processing units (Godjo 2007). This is the case of cassava processing units (Sanni *et al*. 2009), paddy rice processing units (Zossou *et al*. 2009), palm oil and palm kernel processing plants (Alimon 2005) and coconut processing units into oil and milk (Marina *et al*. 2009). It is therefore important to assist the small-scale sector actors with pyrolysis reactor in order to convert biomass waste into energy.

Also, we would like to find other potential sources of biomass that can be used as efficient raw materials.
The goal of this research aims at testing the pyrolysis of Coconut shell, Palm nuts hull, Rice hull shell and Cassava peel and to compare the results of the pyrolysis products with those obtained for Cashew shell.

2. Materials and method

2.1 System design

The pyrolysis reactor was sized to meet the cooking and/or heating energy requirement of a small scale food

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processing products industries with energy needs of about 100 MJ. The schematic diagram of the pyrolysis reactor is shown in Fig. 1.

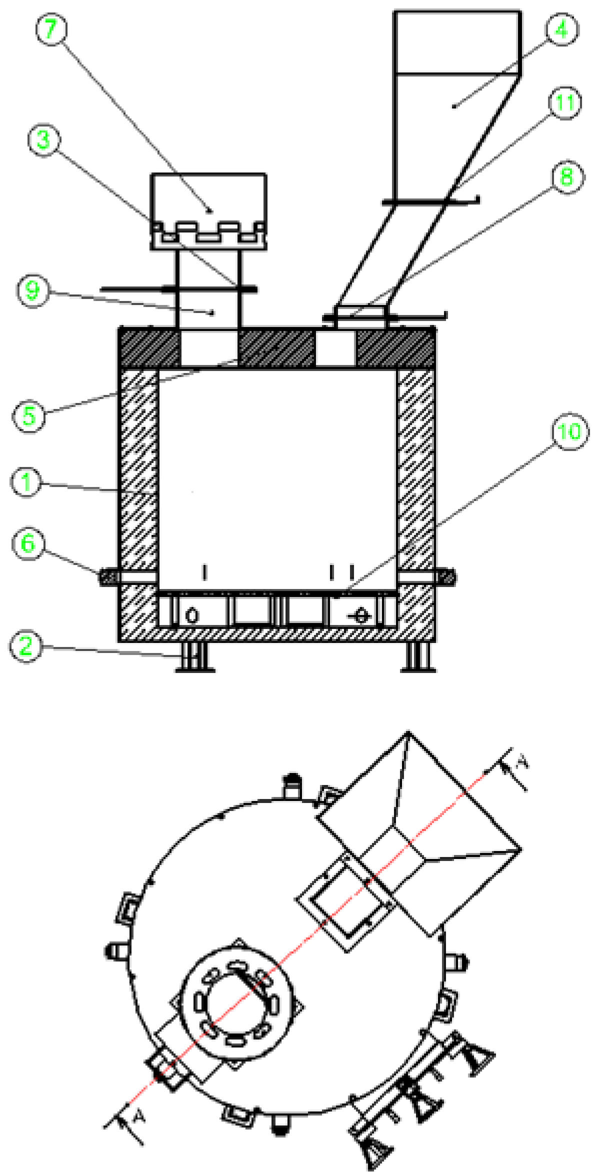

Fig.1 Front and top view of pyrolysis reactor designed

1. Cylindrical reactor
2. Tripod
3. Afterburner Trap
4. Hopper
5. Firebrick
6. Adjustable air opening
7. Afterburner
8. Hopper Trap 1
9. Exit pipe
10. Cast iron grate
11. Hopper Trap 2

The pyrolysis reactor consists of a cylindrical reactor (1) insulated by firebrick (5), cast iron grate (10), adjustable air opening (6), afterburner (7) hopper (4) and exit pipe (9). The reactor is a mild steel (IS 2062) cylinder having diameter of 500 mm and height of 600 mm. The hopper can be open for feeding the vegetable biomass. During the reaction, the traps of the hopper and the top side of the hopper is kept closed by a cover plate tightly secured to the flanged opening. This prevents ingression of atmospheric air into the reactor, thereby achieving pyrolysis conditions. The exit pipe carries away the evolved gases during pyrolysis.

2.2 Raw materials

The cashew nut (*Anacardium occidentale*) shell (Sengar and al. 2012), coconut (*Cocos nucifera. L.*) shell (Siengchum *et al*. 2013), palm nuts (*Elaeis guineensis*) hull (Jia and Lua 2008; Lua, and al. 2006), rice hull (*Oryza sativa. L.*) shell (Tsai *et al*. 2006) and cassava (*Mahihot esculenta*) peel (Moreno-Pirajan and Giraldo 2010a, 2010b) were selected as raw materials.

The physical and thermal properties of raw materials obtained from the previous study and literature (Godjo and al. 2015; Tagutchou 2008 ; Tagutchou and Naquin 2012; Rajvanshi 2014; Bridgwater 2012; Xu and al. 2010; Demirbas and Arin 2002; Sengar and al. 2012; Sangodoyin and Amori 2013; Ezeoha and Akubuo 2014) are given in the table 1.

Table 1 Physical and thermal properties of selected raw materials

Characteristics	Biomass				
	Cashew nut shell	Palm nuts hull	Coconut shell	Rice hull shell	Cassava peel
Bulk density (kg m^{-3})	593	608	593	769	251,1
Moisture content (%)	9.9	9.3	4	3.6	74
Volatile matter (%)	73.5	76.7	77.17	64.7	73.3
Ash content (%)	10.3	1.4	0.3	15.5	3.8
Fixed carbon (%)	14.2	15.7	22.46	15.7	22.8
Calorific value (MJ kg^{-1})	24	17.5	20.8	13.8	18

2.3 Method

Determination of released energy

Released energy was determined by the following formula

$E\ (MJ) = m_{biomass\ total}\ (kg) \times CV_{biomass}\ (MJ/kg)$

Where

$m_{biomass\ total}$ is Total quantity of biomass used

$CV_{biomass}$ is the calorific value of biomass used

3. Results and discussion

3.1 Technical specifications of Pyrolysis Reactor designed

The technical specifications of the pyrolysis reactor designed are presented in table 2.

Table 2 Technical specifications of Pyrolysis Reactor designed

Working principle	
Biomass type	Vegetable biomass, specifically, Cashew nut (*Anacardium occidentale*) shell, Coconut (*Cocos nucifera. L.*) shell, Palm nuts (*Elaeis guineensis*) hull, Rice hull (*Oryza sativa. L.*) shell and Cassava (*Mahihot esculenta*) peel
Biomass properties	Moisture less than 12% (wb)
Diameter	500 mm
Height	600 mm
Capacity	110 l

Table 3 Pyrolysis reactor performance

Biomass	Ignition time (min)	Residence timefor 6.5 kg (min)	Flame temperature (°C)	Pyrolysis products						Released energy (MJ)	Power rating (kW)
				Gas		Char		Ash			
				Mass (kg)	%	Mass (kg)	%	Mass (kg)	%		
Cashew shell	3	120	763	5.5	84.61	1	15.38	-	-	156	21.6
Coconut shell	4	55	715	6.4	98.67	0.1	1.33	-	-	135.72	41.1
Palm nuts hull	10	181	742	4.7	72.31	1.80	27.69	-	-	113.75	10.4
Rice hull shell	7	228	640	5.1	73.08	-	-	1.4	26.92	89.7	6.5
Cassava peel	5	180	680	4.75	78.47	0.75	11	1	10	117	10.8

The pyrolysis of selected vegetable biomasses was carried out in the designed pyrolysis reactor which has small capacity and accommodate about 6.5 kg selected vegetable biomasses (cashew nut shells, coconut shell, palm nuts hull, rice hull shell and cassava peel).

The size selected was suitable for cooking and/or heating energy requirement of a small scale food processing products industries and small amount of burning. The low cost and simplicity of fabrication allowed local development.

3.2 Pyrolysis reactor performance

The performance of the pyrolysis reactor tested with selected biomasses (Cashew nut shell, coconut shell, palm nuts hull, rice hull shell and cassava peel) is given in Table 3.

Preheating time of the biomasses

In the process of pyrolysis, preheat the biomass determines the efficiency of cracking the biomass and meanwhile the performance of pyrolysis (Baumlin 2006). It makes it possible to bring the ring at a temperature which allows the buckling of the biomass in anaerobic conditions. If the biomass is not properly preheated at the start of the process of pyrolysis (when the door of the ferrule is closed), the preheated biomasses off.

It appears from the results above that the cashew nut shells take less time (3 min) to ignite than the other biomasses. Indeed, as we indicated in Table 1, this biomass has a lower calorific value (24 MJ / kg) which exceeds that of the other biomasses (17.5MJ / kg, 20.88 MJ / kg, 13.8 MJ / kg and 18.01 MJ / kg for the nut palm kernel shells, coconut shells, rice husks and cassava peelings). This is what justifies its high buckling capacity compared to other biomass.

Biomass residence time in the reactor

As regards the duration of the pyrolysis, the coconut shells have a relatively shorter time of residence than the other biomasses. This is probably because its volatile matter content (shown in Table 3) which is 77.17% is higher than that of the other biomasses (76.7%, 73.55%, 73.35% and 64. 7% respectively for the palm kernel nut shells , cashew shells, cassava peels and rice balls). Also, we can say that the shorter residence time of coconut shells is due to its morphology. Indeed, coconut shells have more fiber than the other biomasses.

Pyrolysis products obtained

The pyrolysis of the five biomass yielded chiefly gas, char and ash at some places. That of the cashew nuts allows recovering in the form of gas approximately 84.61% of the shell mass processed and yielded approximately 15.38% of the charcoal. These results are close to those obtained by Godjo *et al*. (2015) which were 82% for gas and 18% for the char. However, it was noted during the tests that there was no pyrolysis oil. The absence of pyrolysis oil is certainly due to the pyrolysis temperature because at high temperature, the cracking of the condensable vapors is high and therefore the yield of the gas and the amount of the condensable gas yielded decreases. Moreover, the absence of the pyrolysis oil may also be due to the heating rate at high temperature because, when the heating rate increases, the gas yield increases with a rapid increase in pressure and a brutal expulsion of gases produced and the yield of condensable gases decreases.

The ashes obtained from rice husks and cassava peelings are high (27% and 10%). Indeed, these ashes represent 100% solid for rice hulls and 57.14% for cassava peels. The content of these ashes are certainly due to the physical properties, and especially the texture of the rice husks and cassava peels.

Finally, the energy released by the cashew nut shells is higher (156 MJ) than that released by the other biomasses. This is due to its high calorific value.

The tests were conducted with 6.5 kg of biomass mass. It is clear that with larger quantities of biomass, we will achieve larger amounts of energy. The challenge of thermochemical conversion is not only getting new products (gas tank) forming new chains of added values, but also its ability to transform the energy into other types of energy such as electricity, heat, etc. The conducted tests showed that all the five biomasses studied feature convertible energy.

Conclusions

The designed, manufactured and tested pyrolysis reactor is suitable for Cashew shell, Coconut shell, Palm nuts hull, Rice hull shell and Cassava peel pyrolysis. Furthermore, the results of its products are adapted to small scale processing industries in general and specifically in Benin context. Indeed, the released energies are near (89 – 156) MJ to that used for small scale industrial units (100 MJ). The study substantiates the fact that the selected biomasses are sources of renewable energy. The waste material from coco, palm, rice and cassava processing can now be recycled into usable energy in the processing of these products. Accordingly, this will reduce the operating cost of the cooking.

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