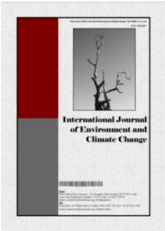

International Journal of Environment and Climate Change

11(7): 80-88, 2021; Article no.IJECC.72494
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

A Review Pyrolysis: Different Agricultural Residues and Their Bio-Char Characteristics

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2021/v11i730442
Editor(s):
(1) Dr. Wen-Cheng Liu, National United University, China.
Reviewers:
(1) G Sujaykumar, Visvesvaraya Technological University, India.
(2) Adefarati Oloruntoba, China University of Petroleum, China.
(3) Adi Surjosatyo, Universitas Indonesia, Indonesia.
Complete Peer review History: https://www.sdiarticle4.com/review-history/72494

Review Article

Received 20 June 2021
Accepted 29 August 2021
Published 08 September 2021

ABSTRACT

Due to the large availability of biomass resources, India has great potential for the production of biochar. Different types of thermochemical even biological processes have been adopted to convert biomass into value-added products. Among those processes, pyrolysis is more convenient since it has several advantages of storing, transportation, and flexibility in solicitation such as turbines, combustion appliances, boilers, engines, etc. Fig. 1 Overview of the pyrolytic product. Illustrates different types of the existing biomass conversion process with their respective output. The study was undertaken to investigate the properties of various agricultural residues. Until recently, the use of BC (biochar) in agriculture was mainly focused on the application of BC as a soil amendment. However, there are opportunities to investigate in this wide field of study, as there are plenty of potential relationships between various parameters, such as (but not limited to) BC(biochar) feedstock material, dose, and its characteristics, type of soil, plant species, and target elements/compounds of the treatment. Other related aspects that were investigated are BC-enhanced composting processes and obtaining the BC via pyrolysis of agricultural waste.

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Keywords: Biomass; bio-char; pyrolysis; properties; temperature.

1. INTRODUCTION

1.1 Biochar Production

The carbonization of wood for biochar production is known to humans from time immemorial. By utilizing waste resources, enhanced biochar technology can contribute to mankind by providing energy needs of the future and also improves soil carbon sequestration potential. There are three widely used technologies involved in the production of biochar namely fast pyrolysis, slow pyrolysis.

2. PYROLYSIS

It is the thermochemical conversion of biomass under a low or no oxygen environment. Pyrolysis can be divided into 3 broad categories namely fast pyrolysis, intermediate pyrolysis, and slow pyrolysis depending upon the process parameters i.e. temperature, residence time, heating rate, the flow rate of sweeping gas. Table 1 and 2 indicated the .Effect of temperature characteristics and yield of products. Also table 3 and 4 was given Physical and thermal properties of various agricultural residues as well as elemental contains. Manavar et. Al. 2021 Calorific value of coconut leaves and briquettes the velue16.42 And 18.64 respectively.

Biowastes are becoming potential feedstocks for direct utilization or conversion to solid, liquid and gaseous fuels via various thermochemical routes.

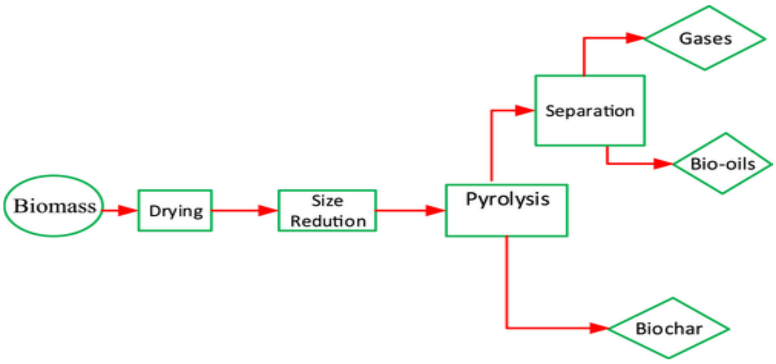

Fig. 1. Overview of the pyrolytic product [1]

Table 1. Effect of temperature on various feedstock characteristics

S. No	Feedstock	Temp. (°C)	pH	VM (%)	FC (%)	Ash (%)	C (%)	H (%)	N (%)	O (%)	Ref.
1	Pig manure	200	8.22	50.70	12.60	35.70	-	-	-	-	[2]
		300	-	-	-	-	-	-	-	-	
		400	-	-	-	-	-	-	-	-	
		500	10.50	11.00	40.20	48.40	-	-	-	-	
		600	-	-	-	-	-	-	-	-	
2	Wheat straw	200	5.43	70.20	22.50	7.21	-	-	-	-	[2]
		300	-	-	-	-	-	-	-	-	
		400	-	-	-	-	-	-	-	-	
		500	10.20	17.60	63.70	18.00	-	-	-	-	
		600	-	-	-	-	-	-	-	-	
3	Pitch pine	200	-	-	-	-	-	-	-	-	[3]
		300	-	-	-	4.50	63.90	5.40	0.30	30.40	
		400	-	-	-	7.90	70.70	3.40	0.40	25.50	
		500	-	-	-	7.70	90.50	2.50	0.30	6.70	
		600	-	-	-	-	-	-	-	-	
4	Safflower seed cake	200	-	-	-	-	-	-	-	-	[4]
		300	-	-	-	-	-	-	-	-	

S. No	Feedstock	Temp. (ºC)	pH	VM (%)	FC (%)	Ash (%)	C (%)	H (%)	N (%)	O (%)	Ref.
		400	8.18	25.20	67.30	7.50	68.76	4.07	3.77	23.49	
		500	9.44	16.50	75.00	8.50	71.37	2.96	3.91	21.76	
		600	9.89	11.60	79.20	9.20	73.72	2.34	3.84	20.10	
5	Canocarpus waste	200	7.37	-	-	4.53	64.19	3.96	0.69	26.61	[5]
		300	-	-	-	-	-	-	-	-	
		400	9.67	-	-	5.27	76.83	2.83	0.87	14.16	
		500	-	-	-	-	-	-	-	-	
		600	12.21	-	-	8.56	82.93	1.28	0.71	6.55	
6	Rapeseed oil cake	200	-	-	-	-	-	-	-	-	[6]
		300	-	-	-	-	-	-	-	-	
		400	-	25.01	57.08	17.91	55.85	2.75	6.47	34.73	
		500	-	20.01	61.45	18.54	56.48	3.22	7.52	32.55	
		600	-	-	-	-	-	-	-	-	
7	Shredded cotton stalk	200	5.88	79.48	15.02	5.5	-	-	-	-	[7]
		300	8.83	72.68	20.23	7.09	-	-	-	-	
		400	9.33	63.16	26.86	9.98	-	-	-	-	
		500	9.68	54.54	32.42	13.04	-	-	-	-	
		600	-	-	-	-	-	-	-	-	
8	Rice husk	200	-	-	--	-	-	-	-	-	[8]
		300	-	-	-	64.19	-	-	-	-	
		400	-	-	-	66.06	-	-	-	-	
		500	-	-	--	66.56	-	-	-	-	
		600	-	-	-	75.35	-	-	-	-	
		700	-	-	-	76.20	-	-	-	-	
9	Cotton straw (CS)	200	-	-	-	-	-	-	-	-	[8]
		300	-	-	-	5.54	-	-	-	-	
		400	-	-	-	8.52	-	-	-	-	
		500	-	-	-	11.45	-	-	-	-	
		600	-	-	-	12.29	-	-	-	-	
		700	-	-	-	12.15	-	-	-	-	
10	Date seeds	350	6.9	-	-	6.7	64.4	-	-	-	[9]
		350	8.6	-	-	-	82.2	-	-	-	
11	Pine woodchips	300	-	-	-	-	63.9	5.4	-	30.4	[10]
		500	-	-	-	-	90.5	2.5	-	6.7	
12	Oxytree prunings	200	-	-	-	-	38.1	7.2	4.6	42.4	[11]
13	Orange peels	300	8.0	-	-	3.9	41.9	6.4	1.8	47.9	[12]
		700	12.3	-	-	-	-	-	0.7	-	
14	Residual wood	300	7.8	-	-	-	45.8	6.1	1.2	44.1	
		700	10.3	-	-	-	-	-	0.5	-	
15	Sawdust	200	-	-	-	0.7	-	-	-	-	[13]
		300	-	-	-	1.7	-	-	-	-	
16	Municipal waste	200	-	-	-	-	-	-	-	-	
		300	-	-	-	-	-	-	-	-	
17	Municipal waste	260	-	-	-	-	59.7	6.1	0.7	13.2	[14]
18	Wastewater sludge	300	-	-	-	-	25.6	2.6	3.3	8.3	[15]
		700	-	-	-	-	20.2	0.5	1.2	-	
19	Sewage sludge	200	-	-	-	43	28.4	2.4	4.0	21.3	[16]
		300	-	-	-	73	12.7	0.7	2.7	9.0	
20	Poultry litter	300	-	-	-	48	38.0	-	-	-	[17]
21	Poultry litter	450	9.9	-	-	-	38.0	2.0	-	-	[18]
		550	13.0	-	-	-	33.0	0.9	-	-	
22	Brewer’s spent grain	300	-	-	-	6.7	55.9	5.8	4.6	24.6	[19]

Table-2. Fate of initial feedstock mass between products of pyrolysis processes [20]

Process	Liquid (bio-oil)	Solid (biochar)	Gas (syngas)
Moderate temperature (~500 oC) Short hot residence time (<2s)	75% (25% water)	12%	13%
Intermediate pyrolysis Low-moderate temperature, Moderate hot vapour residence time	50% (50% water)	25%	25%
Slow pyrolysis Low-moderate temperature, Long residence time	30% (70% water)	35%	35%
Gasification High temperature (>800 oC) Long vapour residence time	5% tar (5% water)	10%	85%

Table 3. Physical and thermal properties of various agricultural residues [21,22]

Properties	Rice husk	Rice straw	Sugarcane bagasse	Cotton stalk	coconut leaves	[21,22]
Bulk density, kg/m^3	331.59	380.54	723.2	206.14	35.57	
True density, kg/m^3	1031.71	1671.97	4594.66	507.36	-	
Porosity	67.86	77.24	84.26	59.37	-	
Angle of repose	37.04	38.23	43.24	43.18	-	
Moisture content (%)	7.52	9.89	11.11	10.01	-	
Volatile matter (%)	70.70	64.43	86.15	96.07	77.00	
Ash content (%)	18.60	15.20	3.28	6.93	6.74	
Fixed carbon (%)	10.7	20.37	10.62	10.7	12.72	

Table 4. Physical properties and Characteristics of bio-char from different feedstock

S No.	Feedstock	pH	Moisture (%)	Ash (%)	VM (%)	FC (%)	C (%)	H (%)	N (%)	O (%)	Reference
1	Safflower seed cake	9.13	-	8.20	20.00	71.80	70.43	3.43	3.36	22.39	[4]
2	Conocarpus wastes	9.67	-	5.27	-	-	76.83	2.83	0.87	14.16	[5]
3	Rice straw	9.68	7.20	15.40	62.40	14.90	44.80	5.10	0.90	49.20	[23,24,25]
4	Pitch pine	-	-	7.90	-	-	70.70	3.40	0.60	25.50	[3]
5	Pine sawdust	-	5.00	0.30	77.70	16.90	50.30	6.70	0.20	42.70	[26,27]
6	Spruce woodchips	10.90	-	31.00	-	-	74.80	0.14	0.15	4.20	[28]
7	Corn stovers	-	2.3	58.00	12.70	28.70	33.20	1.40	0.81	8.60	[29]
8	Coconut shell	9.18	4.40	0.70	80.20	22.00	50.20	5.70	-	43.40	[30,31,24]
9	Peanut shell	9.50	1.90	7.80	8.10	82.20	93.61	1.99	1.05	3.35	[32]
10	Pine cone	9.80	1.20	4.70	6.70	87.40	95.16	2.63	1.61	0.60	[32]
11	Peanut hull	8.60	-	9.30	18.10	-	81.80	2.90	2.70	3.30	[33]
12	Switch grass	8.00	-	7.80	13.40	-	84.40	2.40	1.07	4.30	[33]
13	Pongamia Glabra deoiled cake	11.20	4.30	11.60	14.60	69.50	75.00	3.26	5.00	12.58	[34]
14	Jute dust	-	9.44	10.78	15.07	64.71	70.25	2.78	4.04	22.93	[35]

S No.	Feedstock	pH	Moisture (%)	Ash (%)	VM (%)	FC (%)	C (%)	H (%)	N (%)	O (%)	Reference
15	Sugarcane bagasse	9.30	1.30	8.57	9.17	80.97	85.59	2.82	1.11	10.48	[36]
16	Coco peat	10.30	2.55	15.90	14.30	67.25	84.44	2.88	1.02	11.67	
17	Palm kernel shell (PKS)	6.90	-	6.86	12.29	80.85	87.85	2.91	1.11	8.14	
18	Cotton seed hull	8.50	6.53	7.90	18.60	67.00	87.50	2.85	1.50	7.60	[37]
19	Soybean cake	-	1.50	16.80	10.10	71.60	83.95	1.48	8.32	6.25	[32]
20	Sesame	-	3.40	36.80	22.00	37.80	86.64	3.10	6.93	3.09	[38]
21	Neem	-	3.70	24.50	32.00	39.80	82.34	7.89	5.76	3.57	[38]
22	Mustard	-	4.80	28.10	21.00	46.10	85.43	4.79	6.17	3.41	
23	Shorea robusta seed	-	-	19.70	26.90	53.40	72.58	13.63	4.38	7.74	[39]
24	Shredded cotton stalk	-	-	-	-	-	79.30	1.12	1.53	16.83	[40]
25	Rice husk	9.42	-	-	-	-	28.44	1.0	0.31	7.62	[8]
26	Cotton straw (CS	10.42	-	-	-	-	77.13	2.13	1.03	16.39	
27	Black locust	-	-	-	80.94	-	50.73	5.71	0.57	41.93	[41]
28	Douglas fir	-	-	-	81.50	-	52.30	6.30	0.10	40.50	
29	White fir	-	-	-	83.17	-	49.00	5.98	0.05	44.75	
30	White oak	-	-	-	81.28	-	49.48	5.38	0.35	43.13	
31	Ponderosa pine	-	-	-	82.54	-	49.25	5.99	0.06	44.36	
32	Peach pits	-	-	-	79.12	-	53.00	5.90	0.32	39.14	[41]
33	Walnut shells	-	-	-	78.28	-	49.98	5.71	0.21	43.35	
34	Corncobs	-	-	-	80.10	-	46.58	5.87	0.47	45.46	
35	Wheat straw	-	-	-	71.30	-	43.20	5.00	0.61	39.40	
36	Cotton stalk	-	-	-	70.89	-	43.64	5.81	-	43.87	
37	Corn stover	-	-	-	75.17	-	43.65	5.56	0.61	43.31	
38	Sugarcane bagasse	-	-	-	73.78	-	44.80	5.35	0.38	39.55	
39	Rice hulls	-	-	-	63.60	-	38.30	4.36	0.83	35.45	
40	Pine needles	-	-	-	72.38	-	48.21	6.57	-	43.72	
41	Cotton gin trash	-	-	-	67.30	-	39.59	5.26	2.09	36.38	
42	Wood	-	20	0.4-1	82	17	51.6	6.3	0.1	41.5	[42]
43	Bituminous coal	-	11	8-11	35	45					
44	Hybrid polar	-	45	0.5-2	-	-					
45	Switchgrass	-	13-15	4.5-5.8	-	-	44.77	5.79	0.31	49.13	
46	Miscanthus	-	11.5	1.5-4.5	66.8	15.9					
47	Sugarcane baggage	-	-	3.2-5.5	-	-					
48	Barley straw	-	30	6.0	46	18	45.7	6.1	0.4	38.3	
49	Wheat straw	-	16	4.0	59	21	48.5	5.5	0.3	3.9	
50	Danish pine	-	8.0	1.6	71.6	19					

S No.	Feedstock	pH	Moisture (%)	Ash (%)	VM (%)	FC (%)	C (%)	H (%)	N (%)	O (%)	Reference
51	Rice straw	-	-	64.3	79	10.7					
52	Firewood	-	7.74	1.98	80.86	17.16					
53	Grateloupia filicina	-	4.93	22.37	55.93	17.01					
54	Birch	-	18.9	0.004	-	20	44	6.9	0.1	49	
55	Pine	-	17	0.03	-	16	45.7	7.0	0.1	47	
56	Polar	-	16.8	0.007	-	-	48.1	5.30	0.14	46.10	
57	Scots	-	-	-	-	-	56.4	6.30	0.1	-	
58	Willow	-	-	-	-	-	47.78	5.90	0.31	46.10	
59	Reed canary grass	-	-	-	-	-	45.36	5.81	0.34	48.49	
60	Dactylis lomarata	-	-	-	-	-	42.96	5.70	1.90	49.44	
61	Festuca arundinacea	-	-	-	-	-	42.22	5.64	1.50	50.65	
62	Lolium perenne	-	-	-	-	-	43.12	5.80	1.28	49.80	
63	Olive baggage	-	-	-	-	-	66.9	9.2	-	21.9	
64	coconut shell	-	3.65	2.77	44.77	48.81	73.92	5.6	13.98	3.0	[43]
65	pigeon pea wood	-	9.89	12.3	65.9	21.8	41.1	6.17	0.86	51.9	[44]
66	Soybean	-	-	6.58	76.96	16.46	-	-	-	-	[45]
67	Pigeon pea	-	-	7.05	77.07	15.88	-	-	-	-	
68	Mix biomass	-	-	7.34	79.14	13.52	-	-	-	-	
69	Prosopis juliflora	-	-	1.7	83.05	15.94	-	-	-	-	
70	Leucaena leucocephala	-	-	1.47	82.17	16.94	-	-	-	-	

VM = volatile matter, FC = fixed carbon (moisture, ash, volatile matter and fixed carbon in % and CHNO in wt. %)

3. CONCLUSIONS

- The perusal of the literature showed that the transformation of biomass to value–added products still needs to resolve some trials such as determining the relation between the starting precursors or various feedstock and the overall operation of the pyrolysis.
- Upgrading the consistency of the pyrolysis reactions in terms of complete energy and material alliances to become sustainable for profitable applications.
- Apart from agricultural benefits biochar also possesses some environmental benefits like mitigation of GHG, remediation of polluted soil, and sequestration of carbon. Thus, biochar production and application can be regarded as a viable solution to an array of modern-day problems.

ACKNOWLEDGEMENTS

The authors are grateful for the support of India. Department of Renewable Energy Engineering, Collage of Agricultural Engineering and Technology, Junagadh Agricultural University, Gujarat, Junagadh-362001.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
https://www.sdiarticle4.com/review-history/72494