JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

THERMAL CO-PYROLYSIS OF TENDER COCONUT AND PALMYRA PALM FRUIT WASTES: PRODUCT CHARACTERIZATION AND KINETIC MODELING

[1]MUTHURAJ S, [2]RAJ KUMAR P, [3]SUBIN RAJ M, [4]SUBBIAH JEEVA G

[1]Assistant Professor, [2] Assistant Professor, [3]Assistant Professor, [4]Assistant Professor
[1]Department of Mechanical Engineering,
[1]Loyola Institute of Technology and Science, Thovalai, Nagercoil, Tamil Nadu, India

Abstract: The growing demand for energy and the environmental concerns linked to fossil fuels have accelerated the search for sustainable alternatives. Biomass, an abundant and renewable resource, is a promising feedstock for bioenergy production. Among thermo-chemical conversion techniques, pyrolysis has gained attention for its ability to generate bio-oil, biochar, and syngas. Co-pyrolysis, involving the simultaneous decomposition of multiple biomass types, can enhance process efficiency and product quality through synergistic effects.

In this study, co-pyrolysis of Tender Coconut Waste (TCW, high ash) and Palmyra Palm Fruit Waste (PPFW, low ash) was carried out using thermogravimetric analysis (TGA). Blends were prepared in mass ratios of 0:100, 50:50, and 100:0 (PPFW:TCW). The kinetic parameters were determined using the Kissinger– Akahira– Sunose (KAS) and Friedman models. Results revealed that the 50:50 blend reduced the average activation energy from 61.81 kJ/mol (pure TCW) to 54.09 kJ/mol, indicating improved reactivity due to the synergistic interaction of the feedstocks.

The findings demonstrate that PPFW is a more suitable biomass feedstock compared to TCW, and the 50:50 blend provides an optimal balance for enhanced bioenergy production. This work highlights the potential of co-pyrolysis as an effective strategy for agro-waste valorization and renewable energy generation.

***IndexTerms* – Co-pyrolysis, Tender Coconut Waste (TCW), Palmyra Palm Fruit Waste (PPFW), Thermogravimetric Analysis (TGA), Kinetic Modeling, Kissinger– Akahira– Sunose (KAS), Friedman Model, Activation Energy, Biomass Conversion, Renewable Energy.**

INTRODUCTION

Energy is essential for industrial operations as well as day-to-day human activities. Currently, about 80% of the global energy demand is met by fossil fuels (IEA, 2020), while only a small fraction comes from renewable sources such as solar, wind, tidal, and biomass. However, the excessive dependence on fossil fuels has resulted in harmful emissions, contributing significantly to environmental degradation and global warming. This has necessitated the development of sustainable and eco-friendly alternatives to conventional energy resources.

Biomass, derived from plants and animals, is a promising renewable energy source due to its abundance, carbon neutrality, and potential for energy recovery. Examples include fruit and vegetable residues, husks, straws, and woody biomass. Since raw biomass has limited direct use, it must be converted into energy-rich products through thermochemical processes. Among these, pyrolysis has emerged as an effective technique, as it decomposes biomass into valuable products such as bio-oil, biochar, and syngas under oxygen-free conditions.

Co-pyrolysis is a variant of this process in which two or more feed stocks are thermally decomposed together. Compared to individual pyrolysis, co-pyrolysis often leads to synergistic interactions between feed stocks, resulting in reduced activation energy, improved decomposition behavior, and enhanced quality of pyrolytic products. This makes it a promising approach for bioenergy generation and waste valorization.

In this work, Tender Coconut Waste (TCW), characterized by its high ash content, and Palmyra Palm Fruit Waste (PPFW), known for its low ash content, were selected as feedstocks. The blending of these two biomass residues is expected to improve the efficiency of the pyrolysis process by lowering the activation energy and enhancing product quality. The study focuses on investigating the thermal decomposition characteristics and kinetic behavior of these biomass blends using thermo gravimetric analysis (TGA), providing valuable insights into their potential as renewable energy sources.

II METHODOLOGY OF WORK

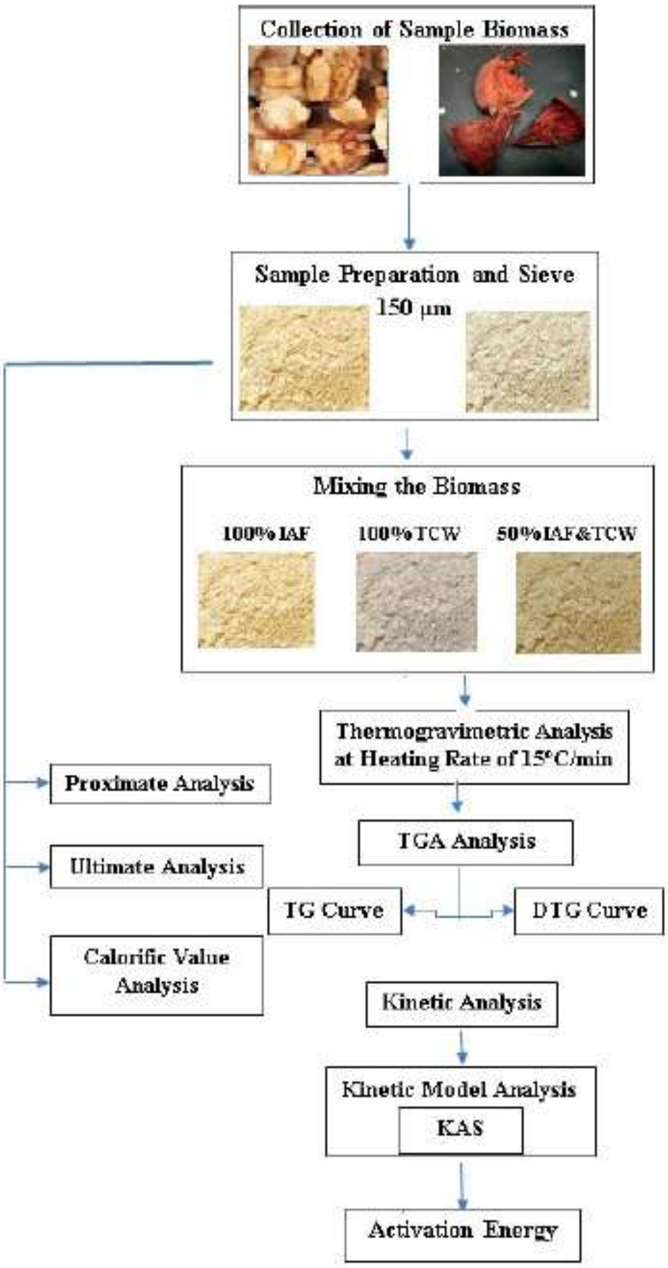

Fig.1.Methodology

III EXPERMENTAL WORK:

FEEDSTOCK PREPARATION: Tender coconut waste and Palmyra Palm Waste was collected from the road side seller. Then it should be clean by water and cut in small pieces and sun dried for 10 to 15 days depend on sunlight is shown in Fig 4.1. Moisture present in the biomass is detached by placed in oven at 80oC for a day, then powdered and sieved to a size of 150 µm. Likewise the mixture is obtained by mixing of 100% TCW, 100% PPW and 50-50 % of TCW and PPW biomass by mass to prepare three samples. Thermo gravimetric analysis in ASTM E1641-18, Standard analyzer with the heating rate of 15o C/min.

Figure 1(a) Photographical images of Palmyra Palm Fruit Waste and its powder

Figure 1(b) Photographical images of Tender Coconut Waste and its powder

III RESULTS & DISCUSSION

A)CHARACTERIZATION OF IAF BIOMASS: The TCW, PPW and its 50% blend biomass was involved into different characterization techniques like ultimate analysis and proximate analysis. In the proximate analysis we had to estimate the The results obtained from the aforementioned analysis are detailed in Table.1

Table1: Proximate, ultimate analysis of Individual TCW and PPFW biomass

Biomass	Proximate analysis				
	Volatile matter (%)	Moisture (%)	Ash (%)	Fixed carbon (%)	Calorific value (MJ/kg)
TCW	52.19	20.87	21.18	5.76	18.04
PPFW	75.27	21.65	2.35	20.97	4.5
Ultimate analysis					
	C	H	O	N	S
TCW	47.97	5.10	41.47	5.12	0.34
PPFW	48.22	4.75	46.23	0.5	0.3

Generally, the gas production ability of the biomass could be identified by conducting the ultimate analysis test. In this work, the ultimate analysis of TCW and PPFW biomass revealed the presence of negligible amount of nitrogen. Further, the sulfur content was not seen. Hence, the possibility for the development of poisonous gases like nitrogen oxides and sulfur oxides are very less. Hence, the TCW and PPFW biomass examined in this investigation is safe for environment and human beings. Calorific value is the amount of heat value present in any material. The calorific value of biomass reveals the energy content of that biomass. Generally, the calorific value of biomass depends on the carbon, hydrogen and oxygen content of the material. Further, it increases with the increase of carbon and hydrogen. Its value decreases with the large content of oxygen. In this work, the calorific value of TCW and PPFW biomass was determined as 18.04 MJ/kg and 4.5 MJ/kg. The higher calorific value of TCW leads to increased temperature encourages the conversion of volatile matter into fixed carbon. Hence the addition of low ash biomass PPFW into high ash biomass to analysis the efficiency of pyrolysis process.

B) THERMOGRAVIMETRIC ANALYSIS (TGA) OF BIOMASS: Thermo gravimetric analysis (TGA) analysis is used to investigate the characteristics of pyrolysis as well as the kinetics of biomass wastes when heat is applied. Thermo gravimetric analysis (TGA) was conducted on the TCW, PPFW and its 50% blended biomass using Thermo gravimetric analyzer of model Q500 from TA instrument. The differential thermo gravimetric analysis (DTG) was done using the TGA data as a function of time and temperature. Experiments were conducted at 15 °C/min heating rate in an inert atmosphere with air flow rate of 200 mL/min at atmospheric pressure.

Thermogravimetric analysis was performed on the TCW, PPFW and its 50% blended biomass and the results are shown in Figure 2 (a) and 2 (b). It was seen from the results that the biomass experienced three stages of thermal degradation. In stage 1, the moisture present in the biomass was evaporated and this stage was ranged in the temperature span of 35 °C to 220 °C.

Stage 2 was ranged from 220 °C to 480 °C which belonged to the starting of decomposition of cellulose and hemicelluloses. In this stage more mass loss was occurred than the previous stage i.e. stage 1.

Stage 3 was noted in the temperature range of 480 °C to 700 °C. The decomposition of lignin was occurred at this stage. Further, the char residue was begun to develop during this stage. This stage required less amount of heat to combusting of biomass.

The PPFW biomass decomposition takes place between the temperature ranges of 159.49oC to 361.46oC. The maximum temperature require to burning of the biomass was 201.35oC. The mass losses occur in the third level is maximum as 26.23% and is lower to 25.89% in the second level. At the end of the combustion process the 42.71% of residue formed as char.

The TCW biomass degradation temperature between the ranges of 189.93Oc to 395.62oC. The maximum temperature require to burning the biomass was 233.06oC. The mass losses occur in the first level is comparatively as very low (0.34%).

The maximum decomposition occur in the third level and the maximum mass loss occur in this level is 36.78%. Hence more amount of heat is required to complete the pyrolysis process. . Mass of the residue exist in the end of the analysis is 46.72%.

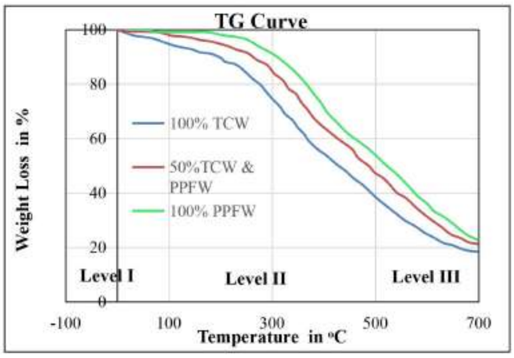

Figure 2 (a) TGA curve of TCW, PPFW and 50 % blended of both biomasses

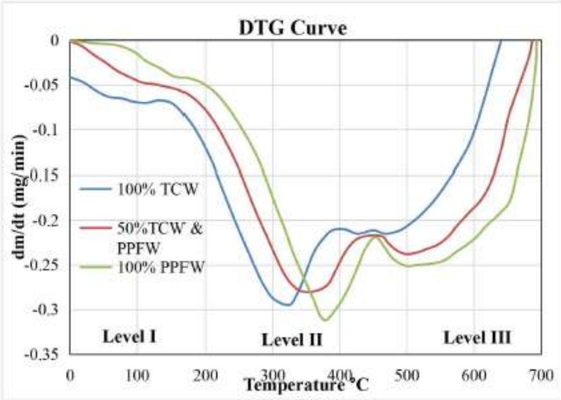

Figure 2 (b) DTG curve of TCW, PPFW and 50 % blended of both biomass

Table 2: TCW, PPFW and 50 % blended of both biomass decomposition data extracted from TG and DTG curves

Sample	Temperature (°C)			Mass loss (%)			Residue at 700°C
	T_i	T_{max}	T_e	Level 1	Level 2	Level 3	
100% TCW	159.49	201.35	361.46	5.17	25.89	26.23	42.71
50-50% Blend	174.48	217.58	378.44	1.81	21.85	31.45	44.89
100% PPFW	189.93	233.06	395.62	0.34	18.25	36.78	46.52

C) KINETIC MODEL ANALYSIS: The kinetic model analysis performed in two kinds of model named KAS and Friedman. The activation energy of the three kind of biomass are extracted with the help of two kinetic model. The graph plot between $ln(\beta/T^2)$& 1/T with different mass fraction of conversion (α)

The activation energy increased gradually from α value in between 0.1 to 0.8. But at the value α = 0.9, the activation energy increased suddenly the maximum value of 118.18 kJ/mol, 133.43 kJ/mol and 54.09 kJ/mol for individual PPFW, TCW and 50% blended biomass respectively.

In Friedman model the activation energy increased gradually from α value in between 0.1 to 0.8. But at the value α = 0.9, the activation energy increased suddenly the maximum value of 134.87 kJ/mol for individual TCW biomass. The activation energy is lower in value in Friedman kinetic model than KAS model. The activation energy value is 29.26 kJ/mol, 57.71 kJ/mol and 43.64 kJ/mol for individual PPFW, TCW and 50% blended biomass respectively.

The activation energy value high ash biomass (TCW) decreased from 57.71 kJ/mol to 43.64 kJ/mol by blending the low ash content biomass (PPFW) into TCW.

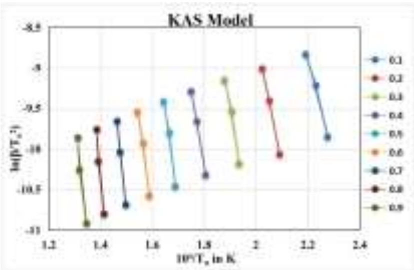

Figure 3(a) KAS plot of TCW biomass.

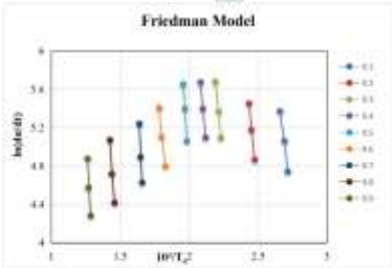

Figure 3(b) Friedman plot of TCW biomass.

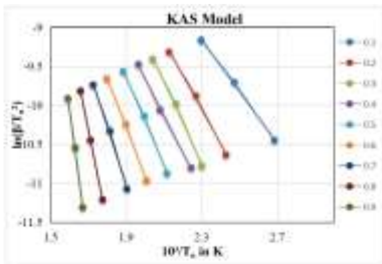

Figure 3(c) KAS plot of PPFW biomass

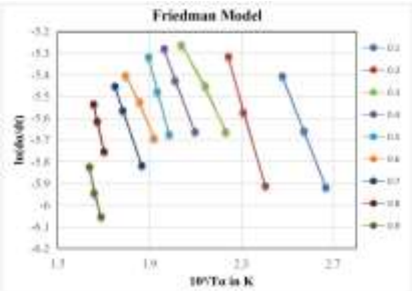

Figure 3(d) Friedman plot of PPFW biomass

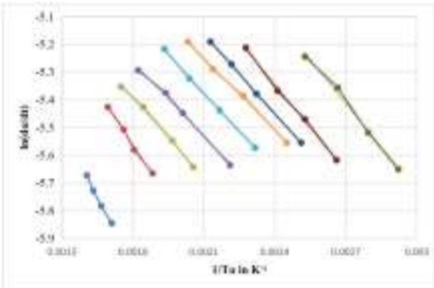

Figure 3(e) KAS plot of 50-50 % blended TCW and PPFW biomass

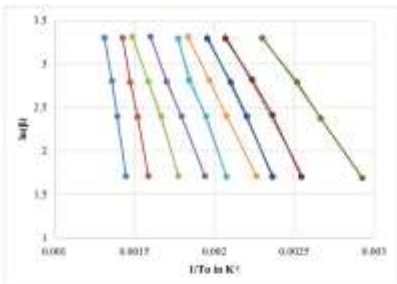

Figure 3(f) Friedman plot of 50-50 % blended TCW and PPFW biomass

Table 3: Activation Energy obtained from KAS and Friedman Kinetic Model of 100% TCW, 100% PPFW and 50% of its blended biomass

A	KAS			Friedman		
	E_{act} (KJ/mole) 100%PPFW	E_{act} (KJ/mole) 50% Blend	E_{act} (KJ/mole) 100%TCW	E_{act} (KJ/mole) 100%PPFW	E_{act} (KJ/mole) 50% Blend	E_{act} (KJ/mole) 100%TCW
0.1	29.68	28.65	27.61	39.68	37.78	35.87
0.2	32.78	34.64	36.49	30.55	33.34	36.12
0.3	42.53	43.24	43.95	17.14	30.80	44.45
0.4	25.82	32.62	39.41	23.55	31.72	39.89
0.5	30.02	38.49	46.96	33.02	40.78	48.54
0.6	17.65	34.80	51.95	19.41	35.92	52.43
0.7	56.60	59.36	62.12	25.88	40.32	54.76
0.8	64.15	81.63	99.10	39.68	56.07	72.46
0.9	118.18	133.43	148.67	37.15	86.01	134.87
Mean	**46.38**	**54.09**	**61.81**	**29.56**	**43.64**	**57.71**

IV SUMMARY:

Biomass has the potential to produce bioenergy which could be used in various applications in industries and home utilities. TCW, PPFW and its 50% blend biomass was investigated for possible source of bioenergy extraction. The TCW, PPFW and its 50% blend biomass was characterized and the thermo gravimetric analysis was done. Results revealed that the TCW biomass showed the energy content value of 18.04 MJ/kg which is comparable with the energy contents of PPFW as 5.4 MJ/kg. Further, it exhibited the very least amount of toxic gases that is no harm to the environment. The moisture present in the TCW biomass was 20.87% as compared to the PPFW biomass which is also near the value as 21.65%. Both biomass value are near to the value of 20% that qualified the biomasses as better candidate in the combustion process. The ignition quality of PPFW biomass is more as compare to the TCW biomass, since the volatile content of PPFW was 75.27% which is higher than the TCW biomass volatile content of 52.19%. The char formation of the pyrolysis process is more in TCW biomass as compared to the PPFW biomass due to the presence of ash content of TCW is more as 21.18% as compared to the PPFW biomass is very low as 2.35%. Further, the combustion process was spontaneous and fast process. In addition, the kinetic analysis showed the average activation energy of PPFW as 46.38 kJ/mol. Also the average activation energy of TCW is more as compared to PPFW biomass is 61.81 kJ/mol. Furthermore the blending of 50% both biomass reduce the average activation energy from 61.81 kJ/mol to 54.09 kJ/mol. This is due to the addition of low ash content biomass (PPFW) to the high ash content biomass (TCW). The experimental result suggest that the PPFW biomass be a good source of bioenergy as compare to the TCW biomass. Also the experiment result shows that the blending of 50% of PPFW and TCW biomass could be a good source for the bioenergy production than the individual TCW biomass.

V CONCLUSION:

In this present investigation, the TCW and PPFW biomass was investigated for the possibilities of bioenergy extraction. The investigation was carried out by performing pyrolysis study and kinetic analysis using the Thermogravimetric analysis.

1. Thermogravimetric analysis of individual and co-pyrolysis of 50% of each biomass results showed that the biomasses was degraded in three stages. Active pyrolysis was occurred from the temperature 220 °C to 480 °C. Furthermore, the passive pyrolysis was happened in the temperature range 480 °C to 700 °C.
2. High mass loss in the temperature range of 480 °C - 700 °C. This was attributed by the simultaneous degradation of cell members such as cellulose, hemicelluloses and lignin.
3. PPFW biomass contain higher fixed carbon (20.97%) as compare to TCW (5.76%), which leads to more char production, hence co-pyrolysis of the two biomass to reduce the char formation.
4. Activation energy value calculated by the different kinetic models such KAS showed an Individual PPFW, TCW and 50% of their blend biomass as 46.38 kJ/mol, 61.81kJ/mol and 54.09 kJ/mol respectively. Also in Friedman kinetic model the activation energy order as 29.56 kJ/mol, 57.71 kJ/mol and 43.64 kJ/mol respectively.
5. In co-pyrolysis process of blended biomass needed less amount of energy to improve the performance of the process as compared to the PPFW biomass based on their volatile matter.
6. The co-pyrolysis process was spontaneous and fast process. This indicated that the given biomass achieved the steady state or thermal equilibrium suddenly.
7. PPFW biomass exhibited the low ash content of 2.35% compared to TCW biomass (21.18 %) which leads to increase the purity of pyrolysis product and to improve the speed of co-pyrolysis **process.**

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