



Kinetic Analysis And Energy Potential Of Biomass Pyrolysis: A Comprehensive Review

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Abstract

Addressing global concerns regarding energy consumption and environmental sustainability, this review paper delves into the pivotal role of biomass and lignocellulosic residues as sustainable energy sources. The composition of these materials, rich in cellulose, hemicellulose, lignin, and extractables, presents significant potential for energy production. Thermal degradation process like pyrolysis, conducted in the absence of air or oxygen, hold promise for converting biomass into valuable chemical substances, including hydrogen gas (H₂). Utilizing thermogravimetric analysis (TGA) allows for the assessment of degradation and mass conversion processes, facilitating the evaluation of kinetic characteristics crucial for forecasting biomass behavior during pyrolysis. For the kinetic parameters of biomass Kissinger, Ozawa-Flynn-Wall (OFW), Kissinger-Akahira-Sunose (KAS) and Coats Redfern methods are considered. This review synthesizes findings from numerous experiments employing pyrolysis and thermogravimetric techniques across over more than fifty biomass types, examining their activation energies and higher heating values as well as proximate and ultimate composition. This review underscores the importance of leveraging diverse biomass sources for thermal and energy generation, providing valuable insights for future research and application in the pursuit of environmentally friendly energy solutions.

Keywords: TGA, Kinetic analysis, KAS, OFW, Coats Redfern

1. Introduction

There is a growing interest in expanding overall energy output and decreasing reliance on fossil fuels due to the increasing popularity of renewable energy sources (Dash et al., 2022). The continuous pursuit of alternative sources of the earth's natural resources involves a diverse scientific community with the objective of achieving an energy transition through the use of bioenergy derived from natural materials. This transition aims to mitigate the existing adverse environmental effects. The demand for alternative bioenergy sources arises from the slow and eventual depletion of oil and its byproducts, as well as the significant environmental issues associated with global warming. Residual solid urban waste may provide energy around 19-21MJ/kg of cellulose and hemi cellulose, a crucial element of any biomass (Dhyani & Bhaskar, 2018). The thermochemical conversion of ligno-cellulosic biomass is often a viable option for generating bioenergy and various chemical compounds.

Biomass are highly regarded for its ecological nature and renewability, making it a promising source for energy development. Recent evidence indicates that the biomass energy comprises 16-35% of the overall primary energy consumed on earth (Khawam & Flanagan, 2006). This emphasises the urgent requirement is to improve scientific researches on organic biomass materials that may use as alternate sources of energy. Annually, several nations, including India, are increasing their output of energy generated from renewable sources. The energy system in India now heavily depends on fossil fuels, constituting around 70% of the primary energy source. Renewable energy accounts for 10% of the total, while biomass provides 5.2%, which is in line with the global norms. The long-term feasibility of energies derived by these biomass sources depends on chemical and technical process, public acceptance for the produced energy by the products, and particular kinds of biomass used for the purpose. Different biomasses possess distinct chemical compositions, molecular and lattice structures, thermos-physical properties, and abilities to produce hydrogen and other valuable compounds. Thermal degradation and other techniques can be used to create energy from biomass materials. Nevertheless, these approaches include difficult mechanisms and involve sophisticated chemical and physical processes it need a comprehensive comprehension of the kinetics and thermal aspects of chemical reaction. The speed of deterioration & activation energy required to chemical reaction both are heavily dependents on factors such as the rate at which the material is heated, kind of biomass being degraded, and the surrounding environment throughout the thermal degradation process (Mastral et al., 2000).

Thermogravimetric analysis (TGA) and its derivative (DTG), offer essential insights into the feasibility, composition, and enhancement of bioenergy derived from biomass. The rapidity and dependability of TGA analysis set it apart from other processes like calorimetry or Van Soest's approach, which need more time and a range of specific reagents (Lopez-Velazquez et al., 2013). TGA analysis is frequently used to investigate the lignocellulosic material degradation reactions and evaluate the impact of heating rate, temperature, and duration on the development of thermal degradation reactions.

Moisture, volatile matter, and important thermal process kinetic parameters including activation energy (E_a), reaction order (n), and the pre-exponential factor (A) are necessary to help the decision maker to choose the suitable bioenergy production process. The characteristics of lignocellulosic biomass can be assessed using a variety of kinetic techniques. Friedman, Horowitz-Metzger, Van Krevelen, Coats-Redfern (CR), Kissinger, -Ozawa-Flynn-Wall (OFW), and Kissinger-Akahira-Sunose (KAS) models are among the models that are used for the estimation of kinetic parameters. These models were specifically created to determine how best to utilise the energy produced by thermal processes like pyrolysis.

2. Literature Review

The present review provides evidence of a wide range of biomass materials, including agricultural biomass, forest waste, and woody(bamboo) residues, that may be used for providing valuable energy and chemical resources. Study utilized the literature review of various studies which showed up the proximate, ultimate composition, and heating value of different biomass. Kissinger, Ozawa-Flynn-Wall, Kissinger-Akahira-Sunose (KAS) and Coats Redfern methods are considered in this review.

2.1 Thermal analysis

The behaviour of heat degradation of various biomass was characterised by thermogravimetric analysis (TGA). This involved exposing a sample to a programmed temperature increase while continuously monitoring its weight loss as a function of temperature. During analysis high-purity nitrogen flow was used to provide an inert environment within the system. By analysing the resulting data, the researchers are able to determine kinetic parameters such as activation energy and reaction order, which provided valuable insights into the pyrolysis process. TGA proved to be an effective tool for characterizing the thermal decomposition of different biomass and assessing its potential as a renewable energy source.

2.2 Kinetic Analysis

To investigate pyrolysis kinetics of different biomasses TGA data at three different heating rates are being used. Kissinger, Ozawa-Flynn-Wall, Kissinger-Akahira-Sunose (KAS) and Coats-Redfern models are being widely used for the computation of kinetics parameters of biomass using TGA data. For the kinetic analysis of various biomass, the pyrolysis temperature range was 200–600°C. The Kissinger technique is used to measure the activation energy (E_a) at the temperature where the highest amount of weight loss occurs. In comparison to the Kissinger approach, which only takes into account the peak temperature (maximum reaction rate) at various heating rates, the KAS and OFW techniques are used to analyse the E_a of biomass/wastes regarding the degree of conversion. Since the OFW, KAS, and Kissinger techniques are often only used to determine E_a , the Coats-Redfern approach is adopted to assess the pre-exponential components for the pyrolysis process. The usual form of the rate equation for the n^{th} order reaction is as follows.

2.3 Kissinger method

A popular method for figuring out the activation energy (E_a) of a thermal breakdown process, such as pyrolysis, using TGA data, is the Kissinger method. When determining the activation energy of a process that adheres to first-order kinetics, this approach is especially helpful. Plotting the natural logarithm of the heating rate (β) divided by the peak temperature (T_m) squared against the peak temperature's reciprocal ($\frac{1}{T_m}$) is the technique's method. This plot's slope multiplied by the gas constant (R) yields the process's activation energy (E_a).

Assuming that the process follows first-order kinetics, the activation energy may be found by examining the plot's slope. This approach is frequently employed in the study of pyrolysis and other thermal processes and offers insightful information on the behaviour of materials during thermal breakdown. With these approaches, estimating the kinetics parameter does not need calculating E_a for each degree of conversion.

$$\ln\left(\frac{\beta}{T_m^2}\right) = -\frac{E_a}{RT_m} + \ln\left(\frac{AR}{E_a}\right)$$

2.4 Kissinger-Akahira-Sunose (KAS)

Based on information from TGA, KAS method calculates the E_a of a thermal degradation process, such as pyrolysis. This approach is not restricted to first-order kinetics and is especially helpful for determining the activation energy of a process that proceeds under non-isothermal circumstances. Plotting the reciprocal of the peak temperature ($\frac{1}{T_m}$) against the natural logarithm of the heating rate (β) divided by the peak temperature (T_m) squared for various conversion levels (α) is the KAS method's technique of analysis. The activation energy (E_a) for the process at each stage of conversion is obtained by multiplying the slope of these plots by the gas constant (R).

$$\ln\left(\frac{\beta}{T_m^2}\right) = -\frac{E_a}{RT_m} + \ln\left(\frac{AE_a}{Rg(\alpha)}\right)$$

The activation energy may be found by examining the plot slopes at various conversion levels. This will provide light on the kinetics of the thermal breakdown process in non-isothermal environments. When first-order kinetics are not precisely followed in a process, the KAS approach is useful for analysing material pyrolysis and heat deterioration.

2.5 Ozawa-Flynn-Wall (OFW)

TGA data is also used for the computation of activation energy in the Ozawa-Flynn-Wall (OFW) method. This approach is not restricted to first-order kinetics and is especially helpful for determining the activation energy of a process that proceeds under non-isothermal circumstances. Plotting the natural logarithm of the heating rate (β) against the temperature at which a specific level of conversion (α) is reached is the OFW technique's method. At each stage of conversion, the activation energy (E_a) for the process is obtained by multiplying the slope of these plots by a constant. The activation energy may be found by examining the plot slopes at various conversion levels. This will provide light on the kinetics of the thermal breakdown process in non-isothermal environments. The OFW technique is useful for researching material pyrolysis and heat deterioration, particularly in situations when first-order kinetics are not precisely followed.

$$\ln(\beta) = \frac{-1.052E_a}{R} \frac{1}{T} + \ln\left(\frac{0.0048AE_a}{R}\right)$$

Based on thermogravimetric analysis (TGA) data, the activation energy (E_a) of thermal breakdown processes is determined using the above mentioned methods such as Kissinger, Kissinger-Akahira-Sunose (KAS), and Ozawa-Flynn-Wall (OFW) techniques. But they are different in a few ways:

1. **Mathematical expressions:** The Kissinger method involves plotting the natural logarithm of the heating rate (β) divided by the peak temperature (T_m) squared against the reciprocal of the peak temperature ($1/T_m$). The KAS method involves similar plots for different levels of conversion (α), while the OFW method plots the natural logarithm of the heating rate (β) against the temperature at a specific conversion level (α).
2. **Kinetic models:** The Kissinger method assumes first-order kinetics, while the KAS and OFW methods do not make this assumption and can be applied to reactions with non-first-order kinetics.
3. **Conversion levels:** The Kissinger method focuses on the peak temperature (T_m) at different heating rates, while the KAS and OFW methods consider the activation energy (E_a) for various levels of conversion (α).
4. **Pre-exponential factor:** The Kissinger method does not provide information on the pre-exponential factor, whereas the KAS and OFW methods can be used to determine this factor.

Processes based on TGA data serve as invaluable tools for investigating the kinetics of pyrolysis and other thermal degradation reactions. By analysing thermogravimetric curves, researchers can extract essential parameters such as the heating rate (β), peak temperature (T_m), activation energy (E_a), gas constant (R), and pre-exponential factor (A). This approach enables a comprehensive understanding of the degradation and mass conversion processes occurring during thermal treatments like pyrolysis. TGA data analysis facilitates the development of kinetic models, allowing for the prediction and optimization of biomass behaviour under varying conditions. Consequently, this method plays a crucial role in advancing research towards sustainable energy production and waste management initiatives.

In summary, while all three methods are valuable for determining activation energy, they differ in their mathematical approaches, consideration of kinetic models, treatment of conversion levels, and ability to determine the pre-exponential factor.

2.6 Coats-Redfern method

The Coats-Redfern method is a technique used to determine the kinetic parameters of thermal decomposition processes based on data obtained from TGA. This method is particularly useful for estimating the pre-exponential factor (A) and reaction order of a process, in addition to providing insights into the activation energy (E_a). Table 1 represents the parameters of Coats-Redfern equation. The general form of the rate equation for the n^{th} order reaction, which is used in the Coats-Redfern method, is as follows:

$$\left(\frac{d\alpha}{dt}\right) = \frac{A}{\beta} e^{\frac{-E_a}{RT}} (1 - \alpha)^n$$

Table 1: Parameters of Coats-Redfern equation.

Parameter	Unit
α (Extent of Conversion)	Dimensionless
T (Time)	Seconds (s)
A (Pre-exponential Factor)	s^{-1} or min^{-1}
Ea (Activation Energy)	Joules per mole (J/mol)
R (Gas Constant)	Joules per mole Kelvin (J/mol·K)
T (Temperature)	Kelvin (K)
n (Reaction Order)	Dimensionless

Table 2 represents the activation energies of different biomass obtained by KAS, FWO, CR methods by analysing the TGA data of different biomass. It shows that the values of activation energies of different biomass for all three models are different. The activation energy of biomass lies in the range of 50 to 270 KJ/mol. Castor beans press cake, residues of fermented cornstalk (FC), Prosopis juliflora, Elephant grass, Scenedesmus sp. and corn stalk are the biomass having high activation energy (>200kJ/mol).

Table 2: Activation energies of different biomass obtained by KAS, OFW, CR methods by analysing the TGA data of different biomass.

Sno	Biomass	KAS (kJ/mol)	OFW (kJ/mol)	Coats Redfern (kJ/mol)	References
1	Wolffia arrhiza	168.35	170.37	-	(Mishra et al., 2020)
2	Musa balbisiana flower petal	137.94	136.76	133.36	(Mishra et al., 2019)
3	Residues of fermented cornstalk (FC)	224.94	224.94	233.46	(Zhang et al., 2009)
4	Prosopis juliflora	164.6	203.2	219.3	(Mishra et al., 2020)
5	Chinese silver grass	-	-	29.3	(Yorgun et al., 2001)
6	Rice husk	-	-	54.3	(Demirbas et al., 2004)
7	Corn stalk	-	-	58.1	(Demirbas, 2006)
8	Sugarcane bagasse	124.54	-	126.62 to 148.80	(Babu & Chaurasia, 2003)
9	Cassava bagasse	144.31	-	157.64 to 227.74	(Galwey & Brown, 1998)
10	Camel grass (Cymbopogon schoenanthus)	169.01	168.57	-	(Zhu, n.d.)
11	Sawdust	35 to 110	35 to 110	-	(Afshari & Jazayeri, 2010)
12	Soybean straw	154.15	156.22	-	(Demirbas, 2006;
14	Wood sawdust	-	-	110.44	(Priyadarsini et al., 2023)
15	Pine sawdust	153.61	-	-	(Zanatta, n.d.)

16	Ramie fabric waste	167.05	169.31	159.66	(Samsudin & Mat Don, 2015)
17	Castor beans press cake	270.6	263.5	193.7	(Yilmaz & Atmanli, 2017)
18	Oil palm empty fruit bunch	-	160.2	-	(Nielsen et al., 2008)
19	De-oiled karanja seed cake	122.8 to 106	126 to 110	-	(Li et al., 2008)
20	Karanj fruit hulls (KFH)	61.06 to 130.49	68.53 to 135.87	-	(G. Mishra & Bhaskar, 2014)
21	Soybean straw	-	-	153.44	(White et al., 2011a)
22	Tucuma endocarp	144.64	147.25	144.64	(Silva et al., 2019)
23	Corn straw	-	-	63.5 to 70.8	(Lang et al., 2019)
24	Elephant grass	221.1, 229.1	218.2, 227.1	-	(Silva et al., 2019)
25	Hazelnut husk	127.8	131.1	-	(Shahabuddin et al., 2020)
26	Rice straw	142 to 170	142 to 170	-	(Shahabuddin et al., 2020)
27	Pinyon pine	-	-	43.9 to 160.3	(Sarkar, 2004)
28	Sugarcane bagasse	77-87.7	43-53.5	-	(Languer et al., 2020)
29	Apple pomace biomass	201.7	213	197.7	(Koski & Sumanen, 2019)
30	Wheat straw	144.05	146.89	-	(Sherren et al., 2019)
31	Scenedesmus sp. Biomass	203.3	202.9	-	(Li et al., 2008)
32	Wheat straw	130-175	130-175	-	(Chandra et al., 2008)
33	Olive residue	204-215	153-162	-	(Jain et al., 2012)
34	Arbutus unedo	90 to 125	125 to 40	-	(Jain et al., 2012)
35	P. hysterophorus	145.44	148.07	-	(Xu & Jiang, 2014)
36	Wolffia biomass	168.35	170.37	-	Ma et al., 2015)
37	Para grass	178.72	188.93	-	(Chai et al., 2015)
38	coconut shell waste	94.7	99.2	-	(Shirai et al., 2017)
39	Soybean straw	154.15	156.22	-	(Ambekar et al., 2017)
40	Tucuma endocarp	160.47	144.64	-	(H & Ma et al., 2018)
41	Ramie fabric waste	167.05	169.31	-	(Baranski et al., 2017)
42	Polysiphoniaelon	126.48	116.23	-	(J & Li et al., 2018)
43	PALF	157.09	94.98	-	(Al-Nimr et al., 2018)

44	SCB	132.57	84.48	(Li et al., 2018)
45	Miscanthus	135.8	229.4	(Ma et al., 2018)
46	Poplar wood	153.92	158.58	(Guan et al., 2018)
47	Corn stalk	211.6	213.3	(Guan et al., 2018)
48	Rice husk	103.2	117.8	(Müller-Hagedorn et al., 2003)
49	Olive cake	112.5	128.1	(Zhai et al., 2016)

Table 3 illustrates the proximate, ultimate analysis and experimental HHV of different biomass. Fixed carbon content, volatile matter and ash content all are useful for determination of feasibility of biomass for its pyrolysis and heat generation. Every biomass feedstock has a different composition depending on its location and other growing factors. It is noted that biomass varies significantly in the compositions such as bamboo biomass has high volatile matter content (86.8%), on the other hand olive kernel has 36% fixed carbon which is highest among all the biomass. Moreover, the ash concentration exhibits significant variation across different biomass samples. Coconut shell exhibits a very low ash percentage of 0.71%, while Rice husk demonstrates a comparatively high ash content of 21.24%. The primary components found in the majority of biomass samples are carbon, hydrogen, and oxygen. Carbon content in biomass samples normally falls within the range of around 38% to 54%. The sulphur concentration in the biomass samples is typically low, with a significant number of samples having zero sulphur content. The composition of any biomass feedstock varies with location and other growth conditions. For any pyrolysis process the sulphur and nitrogen contents of biomass should be low to minimize the environmental hazards (Muigai et al., 2020). Some biomass such as olive kernel, dried grains, wet garnish has a higher heating value than most biomass, and is primarily comprised of volatiles and fixed carbon. Additionally, the study found that there is little to no production of NO_x or SO_x compounds during the consumption of some biomass like Coffee husk, Sugarcane straw, making them an environmentally friendly source of energy.

Table 3: Proximate, ultimate analysis and experimental HHV of different biomass.

Biomass Sample	Proximate analysis (wt.%)			Ultimate analysis (wt.%)					HHV KJ/Kg	Reference
	VM	FC	Ash	C	H	N	O	S		
Pistachio shell	67.85	8.69	14.21	45.53	5.56	1.74	47.17	–	18.57	(Guan et al., 2018)
Coconut shell	77.19	22.1	0.71	50.22	5.7	43.37	–	–	20.5	(Depeursinge et al., 2010)
Wheat straw	82.12	10.98	6.9	42.95	5.35	–	46.99	–	17.99	(Li et al., 2018)
Rice husk	61.81	16.95	21.24	38.5	5.2	0.45	34.61	–	14.69	(Dhyani et al., 2017)
Sugarcane bagasse	83.66	13.15	3.2	45.48	5.96	45.21	0.15	–	18.73	(Açıklın&Gözke, 2021)

Bamboo	86.8	11.24	1.95	48.76	6.32	0.2	42.77	–	20.55	(Wang et al., 2019)
Olive stones	78.3	19.5	2.2	49	6.1	0.8	42	–	20.23	(Mohan et al., 2006a)
Almond shell	80.5	18.4	1.1	48.8	5.9	0.5	43.7	–	19.92	(Singh et al., 2021)
Sunflower seed	84.7	11.7	3.6	51.7	6.2	1	41.1	–	17.6	(Lu et al., 2013)
Esparto plant	80.5	16.8	2.2	46.94	6.44	0.86	43.56	–	19.1	(Matos et al., 2017)
Shea meal	66.3	28.7	5	48.56	5.86	2.88	37.7	–	19.8	(Torres-Sciancalepore et al., 2024)
Sugarcane bagasse	81.5	13.3	5.2	43.79	5.96	1.69	43.36	–	17.7	(Mckendry, 2002)
Cotton stalk	76.1	18.8	5.1	47.07	4.58	1.15	42.1	–	17.4	(Han, 2012.)
Peanut shell	84.9	13.4	1.7	47.4	6.1	2.1	44.4	–	18.6	(Mohomane et al., 2017)
Hazelnut	68.9	30	1.1	50.9	5.9	0.4	42.8	–	19.9	(Nakasaka et al., 2009)
Dried grains	82.5	12.84	3.89	50.24	6.89	4.79	33.42	0.77	21.75	(García-Zubiri et al., 2006)
Wet grains	83.18	13.58	2.58	52.53	6.6	5.35	32.28	0.66	21.95	(Sharypov, 2002)
Corn stover	66.58	26.65	6.73	45.48	5.52	0.69	41.52	0.04	17.93	(Harun et al., 2011)
Coffee husk	78.5	19.1	2.4	47.5	6.4	–	43.7	–	19.8	(Zhai et al., 2016)
Sugarcane straw	76.2	14.6	9.2	43.5	6.1	–	41.1	–	17.19	(Languer et al., 2020)
Marabú	81.3	17.2	1.5	48.6	6.3	–	43.6	–	20.72	(Sarkar, 2004)
Soplillo	77.8	20.7	1.5	48.8	6.5	–	43.2	–	22.58	(Balagurumurthy et al., 2015)
Casuarina leaf	73.5	16.46	3.93	46.12	6.9	1.18	42.64	–	18.48	(Raj & Ghodke, 2024)
Lantana Camara	70.46	11.83	7.26	45.01	6.68	2.02	43.79	–	18.5	(Demirbas, 1998)
Oil palm	78.2	16.46	4.53	45.9	5.8	1.2	40.1	–	16.96	(Harun et al., 2011)
Olive kernel	63.9	32.8	1.7	54.6	6.8	0.8	36.1	–	22.4	(Bilbao, 1987)
Olive kernel	60.5	36.1	3.3	53.2	6.7	0.5	36.3	–	21.4	(Bilbao, 1987)
Olive cake	62.1	34.6	2.8	53.7	6.7	0.6	36.2	–	21.6	(García-Zubiri et al., 2006)
Olive kernel	73.62	24.25	2.13	52.44	6.17	1.32	37.85	0.09	19.9	(Raveendran, 1996)
Forest residue	79.8	20	0.2	53.16	6.25	0.3	40	0.09	19.5	(Mohomane et al., 2017)
Cotton residue	72.8	20.59	6.61	47.03	5.96	1.79	38.42	0.19	16.9	(Mohomane et al., 2017)
Alfalfa stems	78.92	15.81	5.27	47.17	5.99	2.68	38.19	0.2	18.67	(Sharypov, 2002)
Rice straw	65.47	15.86	18.67	38.24	5.2	0.87	36.26	0.18	15.09	(Mohomane et al., 2017)
Switch	76.69	14.34	8.97	46.68	5.82	0.77	37.38	0.19	18.06	(Mohomane et al., 2017)

grass										al., 2017)
Willow wood	82.22	16.07	1.71	49.9	5.9	0.61	41.8	0.07	19.59	(Nakasaka et al., 2009)
Hybrid poplar	84.81	12.49	2.7	50.18	6.06	0.6	40.43	0.02	19.02	(Mohan et al., 2006b)
Almond hulls	73.8	20.07	6.13	47.53	5.97	1.13	39.16	0.06	18.89	(R. K. Mishra, Lu, et al., 2020a)
Oak wood Small branch	77.45	18.5	4.05	48.76	6.35	2.81	42.08	–	19.2	(Wang et al., 2019)
Oak wood medium branch	80.82	16.18	3	48.62	6.52	2.58	42.28	–	19.24	(Mohan et al., 2006a)
Oak wood large branch	81.75	16.18	2.07	48.57	6.81	2.39	42.23	–	19.17	(Mishra.,et al., 2020b)
Pine wood	72.4	21.65	5.95	49.66	5.67	0.51	38.07	0.08	19.79	(Lu et al., 2013)
Corn straw	73.15	19.19	7.65	44.73	5.87	0.6	40.44	0.07	17.68	(Perea-Moreno et al., 2019)
Rape straw	76.54	17.81	4.65	46.17	6.12	0.46	42.47	0.1	18.34	(Perea-Moreno et al., 2019)
Palm kernels	77.28	17.59	5.14	48.34	6.2	2.62	37.44	0.26	20.71	(Yousef et al., 2020)
B-woodb	76.53	21.62	1.85	50.26	6.91	1.03	39.66	–	20.05	(Yaman, 2004)
Pepper plantb	64.71	20.86	14.44	36.11	4.26	2.72	41.86	0.49	15.39	(White et al., 2011b)
Biomass mixb	69.36	18.14	12.49	49.59	5.79	2.43	28.87	0.74	18.4	(Rony et al., 2019)
Sugarcane bagasse	82.6	14.7	2.7	47.2	7	–	43.1	–	17.32	(Qi et al., 2024)
Ipil ipilb	79.9	17.7	2.4	48.3	6.8	–	42.5	–	20.22	(Mckendry, 2002)
Rice huskb	61.2	16.3	22.5	38.2	5.6	–	33.7	–	16.47	(Takaguchi et al., 2014)
Olive pittsb	82	16.28	1.72	52.8	6.69	0.45	38.25	0.05	21.59	(Nawaz & Razzak, 2024)
Pistachio shell	81.64	16.95	1.41	50.2	6.32	0.69	41.15	0.22	18.22	(Wu & Wu, 2013)
Almond shell	76	20.71	3.29	49.3	5.97	0.76	40.63	0.04	19.49	(Mohan et al., 2006b)

3. Conclusion

In conclusion, our review paper has provided valuable insights into the energy potential and feasibility of various biomass sources for thermal and energy generation. The comprehensive biomass pyrolysis kinetic research has been reviewed in this work. KAS, Kissinger, and OFW and Coats-Redfern method are reviewed. The Kissinger method assumes first-order kinetics, while the KAS and OFW methods can be applied to reactions with non-first-order kinetics. Our analysis reveals that the activation energy for different biomass samples typically ranges from 50 to 270 kJ/mol, with Castor beans press cake, exhibiting the highest activation energy at 270 kJ/mol, and rice and Chinese silver grass showcasing the lowest (<53kJ/mol). It is noteworthy that biomass compositions vary significantly across different sources,

with bamboo biomass showing a high volatile matter concentration (86.8%), while olive kernel exhibit the highest fixed carbon content (36%). The predominant constituents in most biomass samples include carbon, hydrogen, and oxygen, with carbon concentrations typically ranging from 38% to 54%. Additionally, biomass samples generally contain low levels of sulphur. These findings underscore the promising outlook of biomass as a sustainable energy source, particularly in waste-to-wealth facilities aimed at replacing thermal energy.

Reference

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