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Exploring ash fusion characteristics and thermal decomposition of biomass through thermogravimetric analysis

Sachin Channappa Hallad^{1*}, N. L. Panwar¹ and V. Kavan kumar¹

Abstract

This study aims to investigate the ash fusion properties along with thermogravimetric examination of different biomass in an inert atmosphere at 20, and 30 °C/min. According to the accepted procedures, the physicochemical characterizations of biomass Sawdust, Soybean (*Glycine max*) as well as Eucalyptus (*Eucalyptus globulus*) were completed. Thermodynamic and kinetic parameters were determined within the active pyrolysis zone using iso-conversional models like FWO and KAS techniques. During thermal deterioration, biomass loses mass through moisture loss, passive and active pyrolysis. The active pyrolysis zone was responsible for 50–55% of the mass loss between 180 and 395 °C. The activation energy values were 175.08 and 174.21 kJ/mol based on KAS and FWO models, respectively, for sawdust; 153.15 and 151.47 kJ/mol for soybean and for eucalyptus 168.70 and 167.70 kJ/mol, respectively. The ash fusion behaviours of biomass showing 1506 °C deformation temperature for soybean followed by 1465 °C for eucalyptus and 1289 °C for sawdust and their variation processes under decreasing atmosphere were examined to reduce ash-related problems during gasification.

Keywords Biomass, Thermogravimetric analysis, Iso-conversional models, Ash fusion behaviour, Deformation temperature

Introduction

An important tool for decarbonizing the power sector and reducing the consequences of greenhouse gases and climate change is using renewable energy sources (Sinsel et al., 2020). The environment is harmed, and the widespread usage of fossil fuels destroys live species and territories. As a result, numerous researchers have sought to develop remedies utilising renewable energy sources (Algarni et al., 2023). In addition to being supplied to fulfill current and future energy needs, renewable energy sources also provide answers for sustainable development (Tan et al., 2021).

Biomass is a renewable energy source that has received much global attention for various uses, including combustion because of its widespread distribution, low nitrogen and sulphur content, and zero carbon emissions (Kumar et al., 2022; Li et al., 2021). Biomass energy makes an important renewable energy source, which shows a promising application to derive an alternate energy to replace fossil fuels as well as can play a pivotal role in biobased economy (Demirbas et al., 2009; Pant et al., 2019). The capacity of biomass to satisfy the energy needs of today's society is quite great. Production of biomass in India ranges from 450 to 500 million tonnes 32% of the country's total primary energy consumption comes from biomass (Ghosh, 2021). A total of 260 million tonnes of coal might be replaced by biomass. This might save the country about 250 billion rupees yearly (IREDA, 2022). Direct combustion, biochemical conversion, and thermochemical conversion

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Table 1 Recent ash fusion tests conducted by some of researchers

Materials used	Additives	Working conditions	Results	Refs.
Iron-rich Zhundong coal	Halloysite, alumina-rich ash, dolomite, SiO_2 , CaO and MgO	Temperatures of 1100, 1150 and 1250 °C	Coal ash melting can be inhibited by the formation of MgFe_2O_4 , FeAl_2O_4 , $\text{Mg}(\text{FeAl})_2\text{O}_4$, or MgAl_2O_4 due to the addition of alumina-rich ash, MgO, and dolomite composite additive	Wang et al., (2022a)
Zhundong coal	Co-combustion with coal gangue	10, 20, 30, 40 and 50% Coal Gangue mixed with coal	As the amount of CG increases from 10 to 50%, the ash fusion temperatures of the ZC–CG ash, which includes DT, ST, HT, and FT, typically increase initially before decreasing to approach their maximums at 40% CG	Deng et al., (2021)
High sodium coal [Luan (LA) and Hongshaquan (HSQ)]	Ammonium dihydrogen phosphate and tricalcium phosphate	Gasification conditions	The AFTs of high sodium coal increase, When phosphorus-based additives are used and the diffraction intensity of quartz and phosphates increases when the $\text{PO}_4^{3-}/\text{Na}$ molar ratio increases	Zhang et al., (2022)
Zhundong coal	Purified dust (PD) and removed dust (RD) from calcium carbide production	Ash production temperatures at 1150/1250 °C. Additive percentage of 2.5, 5.0 and 7.5 wt%	ZD coal blends with high Ca and low Si would exhibit a significant reduction in their high temperature melting behaviour when the CaO/SiO_2 molar ratio was kept within the range of 2.2–3	Wang et al., (2022b)
sewage sludge (SS), petrochemical sludge (PS),	Co-firing with wheat straw (WS)	WS of 10, 20, 30, 40, 50, 60, 70, 80, 90% mixed with sludge	High melting point silicates, silicon dioxide, and ferric oxide are found to be the mineral materials in the SS–WS ash, whereas high melting point phosphate, manganese aluminate, silicon dioxide, and aluminium nitride are identified in the PS–WS ash	Deng et al., (2020)
Torrefied woody biomass	–	Torrefaction temp. (220, 240, 260, 280, 300 and 320 °C) at 60 min	The investigation concluded that raising the torrefaction temperature improved the thermal characteristics of the torrefied biomass without changing the ash fusion temperatures or biomass ash compositions	Adeleke et al., (2020)
Yunnan coal (YNC) and Guizhou Coal (GZC)	Oat Straw (OS), Poplar Wood (PP), Rosewood (RW) and Rice Husk (RH)	10 and 30 wt% of biomass mix with coal	As seen by the ash fusibility index, the results demonstrated that mixing the coal with the Alkali and Alkaline Earth Metals (AAEMs) rich biomass reduced the slagging propensity	Oladejo et al., (2020)

Table 1 (continued)

Materials used	Additives	Working conditions	Results	Refs.
Peanut shell pellets, Wheat straw and corn straw pellets	–	Ash fusion temperatures range at 1100/1300 °C	The three biomass pellets' combustion reactivity was enhanced by the ash melting process at 1300 °C, with the corn straw pellets exhibiting the most noticeable combustion reaction. Only peanut shell pellets combustion reactivity was enhanced by the ash melting process at 1100 °C, but corn and wheat straw pellets combustion reactivity was hindered	Zhai et al., (2022)

Table 2 Physico-chemical properties of different biomasses

Analysis	Sawdust	Soybean	Eucalyptus
Proximate analysis			
Moisture content (%)	7.55	9.48	8.62
Volatile matter(%)	80.17	78.63	78.64
Ash content(%)	5.47	6.26	3.13
Fixed carbon(%)	6.81	5.61	9.61
Ultimate analysis			
C	43.87	47.62	47.83
H	8.50	6.85	6.21
O	52.36	42.56	45.58
N	0.54	1.10	0.51

are the three main types of biomass conversion processes. It is usual practise to use thermochemical processes like combustion, liquification, and gasification to transform biomass into fuels with increased heating value.

Ash fusion temperature (AFT) testing is a widely used laboratory technique, because it indicates the melting behaviour of ash with respect to temperature. While ash fusion measurements consider visual changes such as changes in the shape of specimen caused by viscosity changes. These AFTs possess following attributes and applications. They give the temperature range, where the deposits on the heat-absorbing surfaces could occur (Özbayoğlu & Evren Özbayoğlu, 2006). This provides crucial hints on how much ash agglomeration and clinkering will likely occur within the boiler/gasifier. Alkali metals and alkali earth metals, which are present in high concentrations in most biomass, cause a sticky deposit layer deposition on the heated surfaces during combustion. The engineers and operators of furnaces and boilers in power generation plants frequently use their knowledge of AFTs to forecast coal ash's melting and sticking behaviour (Tambe et al., 2018). The previous ash fusion test works carried out by various researchers is indicated in Table 1.

To characterise the ash melting process, ash fusion temperatures are divided into four categories: initial deformation temperature (DT), softening temperature (ST), hemispherical temperature (HT), and flow temperature (FT). ST was a performance measure used to assess coal ash fusion. However, DT was used for biomass due to ST, HT, and FT's lack of sensitivity to the components

contained in biomass ash (Fang & Jia, 2012; Liu et al., 2018).

Based on the previous studies conducted on the ash fusion test of coal and some biomasses. Still, the research is required to achieve the best results in comparison with the conventional coal. Hence, in this study different biomasses were selected for the evaluation of different ash fusion temperatures is done as the ashes inclination to adhere to heat transfer surfaces increases with melting, which can lead to fly ash deposition on the heating surface and affect the combustion device's economy, dependability, and safety. The phenomena responsible for this ash deposition are termed slagging and fouling. This can impact biomass gasification products and decrease the equipment's utilisation efficiency and operational time. The thermogravimetric (TG) analysis was carried out at two different temperatures of heating along with the iso-conversional models like Kissinger–Akahira–Sunose (KAS) and Flynn–Wall–Ozawa (FWO) method to study the thermal and kinetic compatibility of selected biomass.

Materials and methods

Three different kinds of biomass fuels, including Sawdust, Soybean (*Glycine max*) as well as Eucalyptus (*Eucalyptus globulus*) were utilized in the study. These biomasses were selected to reflect the wide range of ash components and their applications, which are already being utilised or will be in boiler fuels in the future.

Physicochemical properties

Standard methods ASTM (D3174, D3173, and D3175) were used to measure the moisture, ash, and volatile matter of selected biomass samples, respectively, and the obtained results are mentioned in Table 2.

Thermo-gravimetric analysis

The generated Biomass material was examined in a Hitachi STA7300 thermogravimetric analyzer to determine the feedstock's thermal degradation pattern. The finely milled material is heated at 20, and 30 °C/min during TG analysis at temperatures ranging from 30 to 900 °C. Nitrogen (N₂) gas was supplied at an 80 ml/min flow rate throughout all of the experimental runs to prevent undesirable oxidation reactions inside the pyrolysis zone. Using Origin Pro software, the differential thermogravimetric values (DTG) were updated with the aid of TG data.

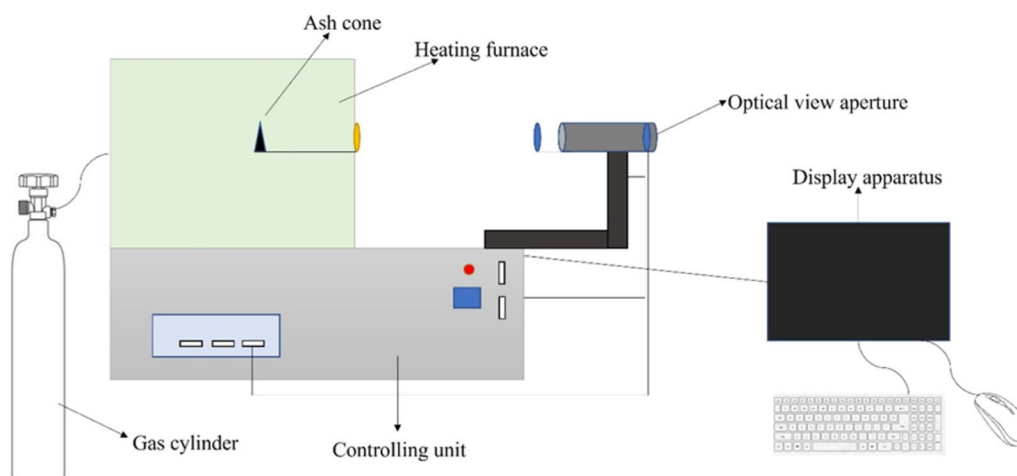


Fig. 1 Schematic diagram of ash fusion tester

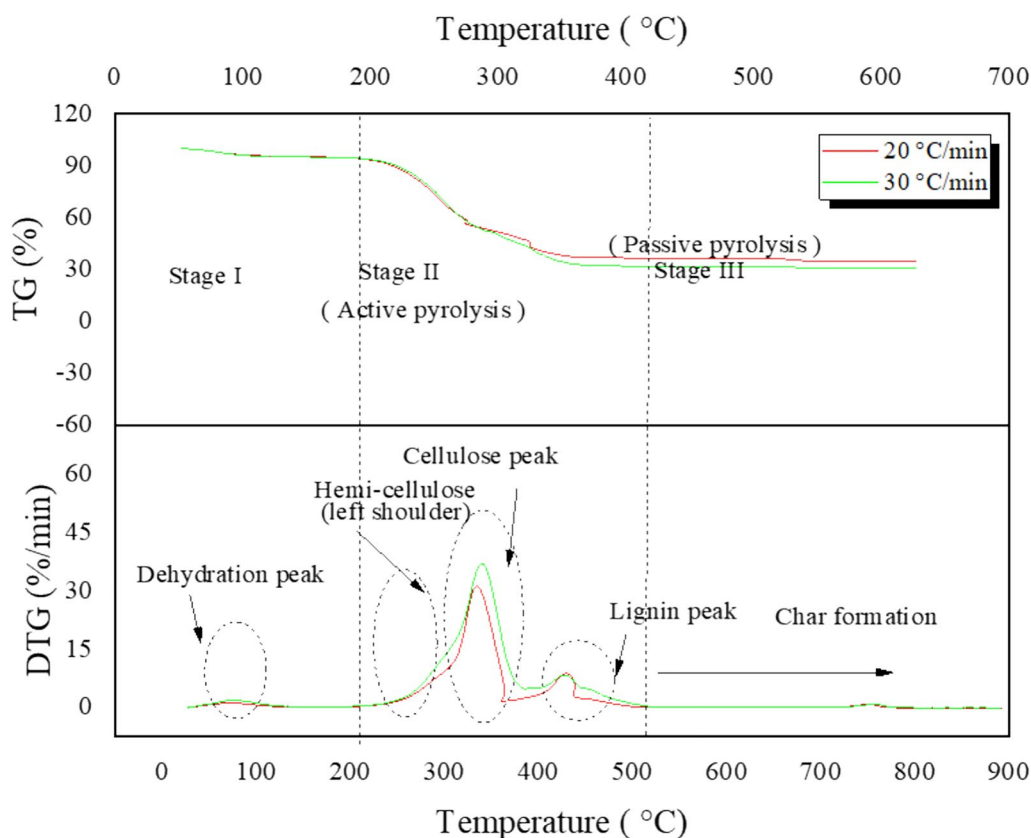


Fig. 2 Thermal decomposition behaviour of sawdust at heating rate of 20 °C/min and 30 °C/min

Kinetic study

Biomass pyrolysis is a complex process as several reactions are taking place. It is typically impossible to do a comprehensive kinetic analysis of the complicated system, but some effective or average kinetic descriptions

are still required. The iso-conversional Flynn–Wall–Ozawa (FWO) method, Kissinger–Akahira–Sunose (KAS) method, Starink method as well as the Fredman approach, were used on TGA data of eucalyptus, soybean

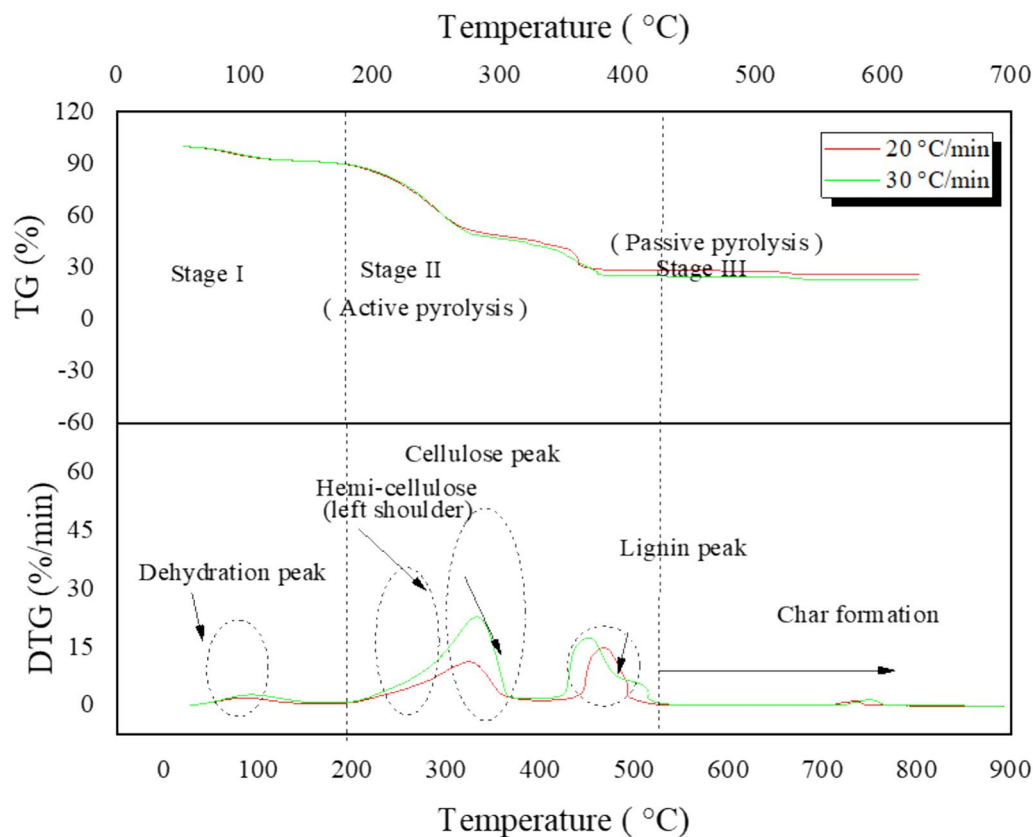


Fig. 3 Thermal decomposition behaviour of soybean at heating rate of 20 °C/min and 30 °C/min

straw and sawdust in this study to evaluate the pyrolysis reaction kinetics.

Kissinger–Akahira–Sunose (KAS) method

The following formula is used to calculate the E (activation energy) using the KAS, a model-free iso-conversional technique.

$$\ln \left(\frac{\beta}{T^2} \right) = \ln \left(\frac{AE_a}{Rg(\alpha)} \right) - \frac{E_a}{RT}$$

the activation energy determined using the equation's slope and the relationship between $\ln \left(\frac{\beta}{T^2} \right)$ and $1/T$. When calculating activation energy, the slope of a straight line ($E \propto R$) is used. It offers more accurate or precise activation energy estimations when compared to FWO(Starink, 2003).

Flynn–Wall–Ozawa (FWO) method

An iso-conversional technique without models is the Flynn–Wall–Ozawa method. Plotting $\ln \beta_i$ versus $1/T_{ai}$ for a given conversion value ($E\alpha$) at various heating rates (β) will yield the activation energy (E) and the expression for this kinetic model is expressed as

$$\ln(\beta) = \ln \left(\frac{AE_a}{Rg(\alpha)} \right) - 5.311 - 1.052 \left(\frac{E_a}{RT} \right)$$

where the rate of heating is constant for any value of i and $g(\alpha)$. E (activation energy) is estimated using the $1.052 \left(\frac{E_a}{RT} \right)$.

Ash preparation

The air-dried raw materials subsequently heated to 750 °C in the muffle furnace for 90 min. The ashes were then taken out and allowed to cool to normal temperature.

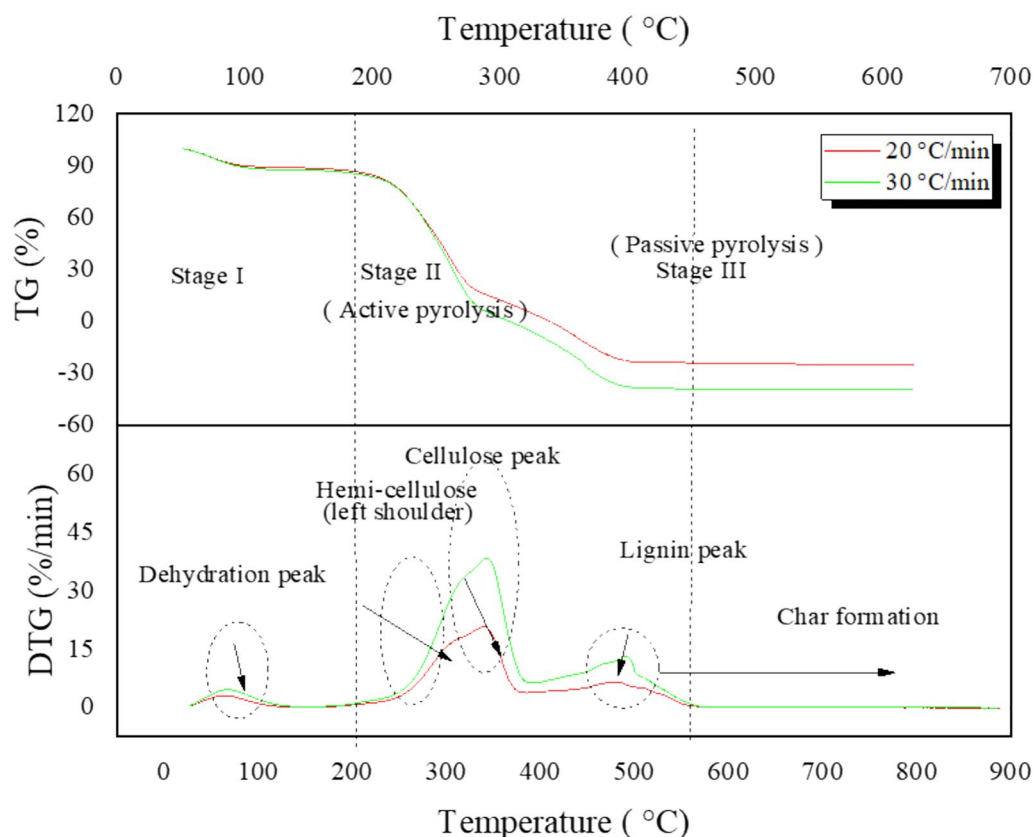


Fig. 4 Thermal decomposition behaviour of eucalyptus at heating rate of 20 °C/min and 30 °C/min

Ash cone preparation

Take out ash and place it on a piece of glass or other smooth and clean plate, wet it with dextrin solution and mix it thoroughly to the status of shapeable, and move it to the ash mould and extrude it with sharp knife to form cone shaped ash. When the surfaces of the ash cones become a little drier, move the cones carefully from the mould to the glass or other smooth and clean plate by blade to make it air dried or put it into the drying oven and dry under the temperature of 60 °C, make it ready to use in further experiments.

Ash fusion test

The biomass ash cones were directly used for the experiments on an ash fusion tester (model FTS-02, see Fig. 1). The ash fusion tester temperature was set to 1500°C but in case of soybean it has reached the set temperature without achieving the melting temperatures so later the temperature is set to 1600°C. Based on changes in the

shape of the ash-cone during the process, the deformation temperature (DT), softening temperature (ST), hemispheric temperature (HT), and flow temperature (FT) were measured.

The deformation temperature (DT) is the temperature at which the first signs of rounding of the edges of the test piece occurs due to melting, the softening temperature (ST), is the temperature at which the base of the cone is equal to its height, the hemispherical temperature (HT) is the temperature at which the test piece forms a hemisphere (i.e., the height becomes equal to half the base diameter) and the flow temperature (FT) is the temperature at which the ash is spread out over the supporting tile in a layer.

Results and discussion

Characteristics of biomasses

See Table 2.

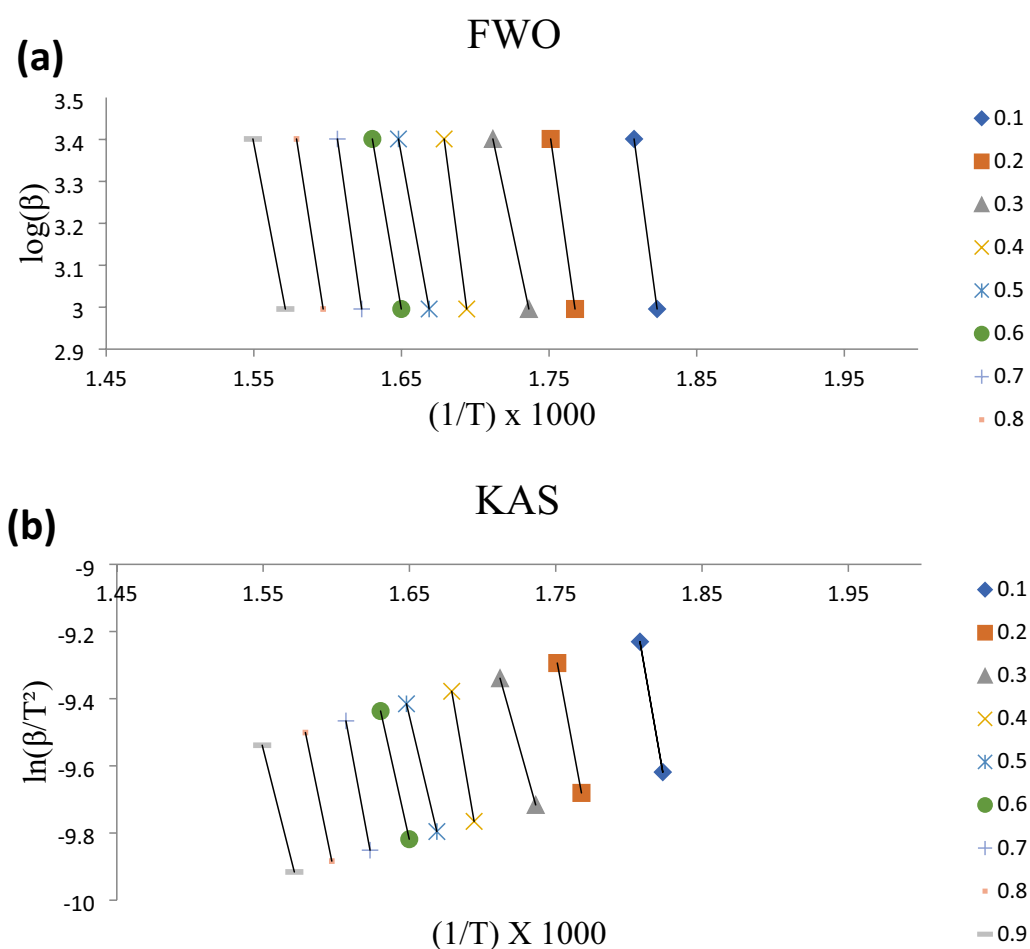


Fig. 5 **a** Linear plots for sawdust using FWO method for calculating the activation energy. **b** Linear plots for sawdust using KAS method for calculating the activation energy

Thermogravimetric analysis of biomasses

TGA analysed the thermal stability and weight loss of the biomasses at heating rate of 20, and 30 °C/min is shown in Figs. 2, 3 and 4, respectively. The obtained TGA curves were divided into three phases: moisture removal, devolatilization, and biochar formation. The physically and externally bonded moisture in biomass is initially removed at temperatures below 200 °C. Pyrolysis, hemicellulose, and cellulose thermally degrade in the second stage, with the rate of decomposition reaching its maximum. The left and right sides comprise the second phase's two sections. Hemicellulose breakdown is seen on the left side. Because biochar has few volatile components, it degrades more slowly at moderate temperatures (Ferrara et al., 2014; Mahendiran, et al., 2023). Figure 2 shows the initial deterioration peak in the DTG

curve, which is divided into three stages: Stage I of the dehydration phase includes the release of some moisture and extractives. Stage II is the active pyrolysis zone, during which 50–55% of the mass is lost. Hemicellulose and cellulose degradation produces the first peak on left side. Stage III, when lignin degradation took place. The slower pace of reaction and improved heat resilience of lignin necessitate a higher temperature (100–900 °C) for full degradation (Chen et al., 2018; Díez et al., 2020; Ma et al., 2018).

Due to the hygroscopic nature of soybean straw and the presence of extremely light volatiles, the first one, ranging from 80 to 120 °C, corresponded to the amount of moisture that the samples contained. The primary breakdown process occurred between 210 and 370 °C, with a high peak occurring at roughly 320 °C, which the pyrolysis of

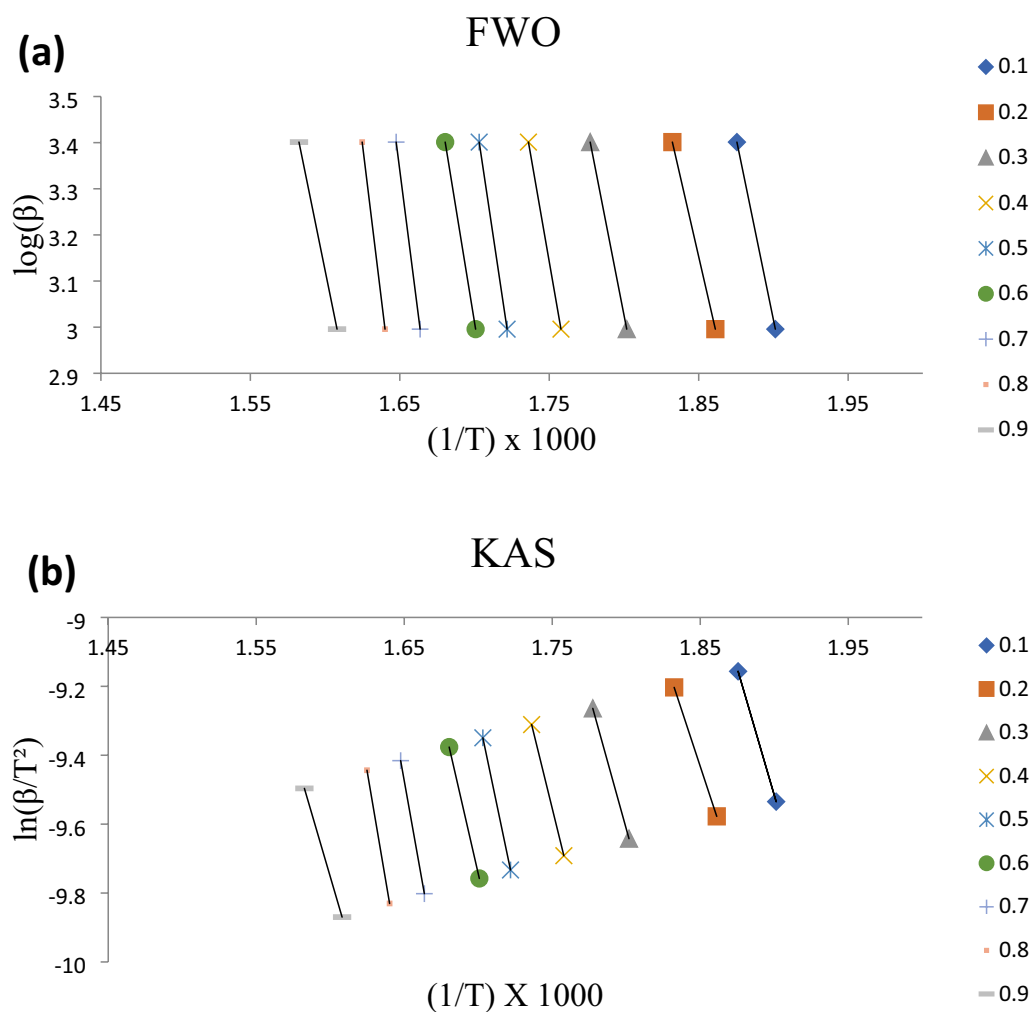


Fig. 6 **a** Linear plots for soybean using FWO method for calculating the activation energy. **b** Linear plots for soybean using KAS method for calculating the activation energy

hemicellulose and cellulose may have brought on. After the stage, a shoulder between 440 and 530 °C was seen, which should be connected to the lignin's degradation. For sawdust and eucalyptus, dehydration temperature range between 70 to 110 °C and 60 to 100 °C. Hemicellulose and cellulose breakdown took place at temperatures of 230–360 °C and 220–380 °C with lignin degradation occurring between 360 to 500 °C and 380 to 550 °C temperature, respectively. Furthermore, the char formation occurred up to 900 °C.

Kinetic analysis

The apparent activation energy of sawdust, soybean and eucalyptus calculated using FWO and KAS are displayed in Figs. 5a, b, 6a, b, and 7a, b. The kinetic characteristics of sawdust, soybean and eucalyptus, such as A (pre-exponential factor) and E (activation energy), were determined using iso-conversional techniques. Activation energy and Thermodynamic parameters like Enthalpy, Gibbs-free energy and Entropy of sawdust, soybean and eucalyptus are tabulated in Tables 3, 4 and 5, respectively.

As per Table 6, the obtained results in this study were compared to the previous studies of the different biomasses, where as the obtained values of activation energy for sawdust, soybean and eucalyptus were almost in

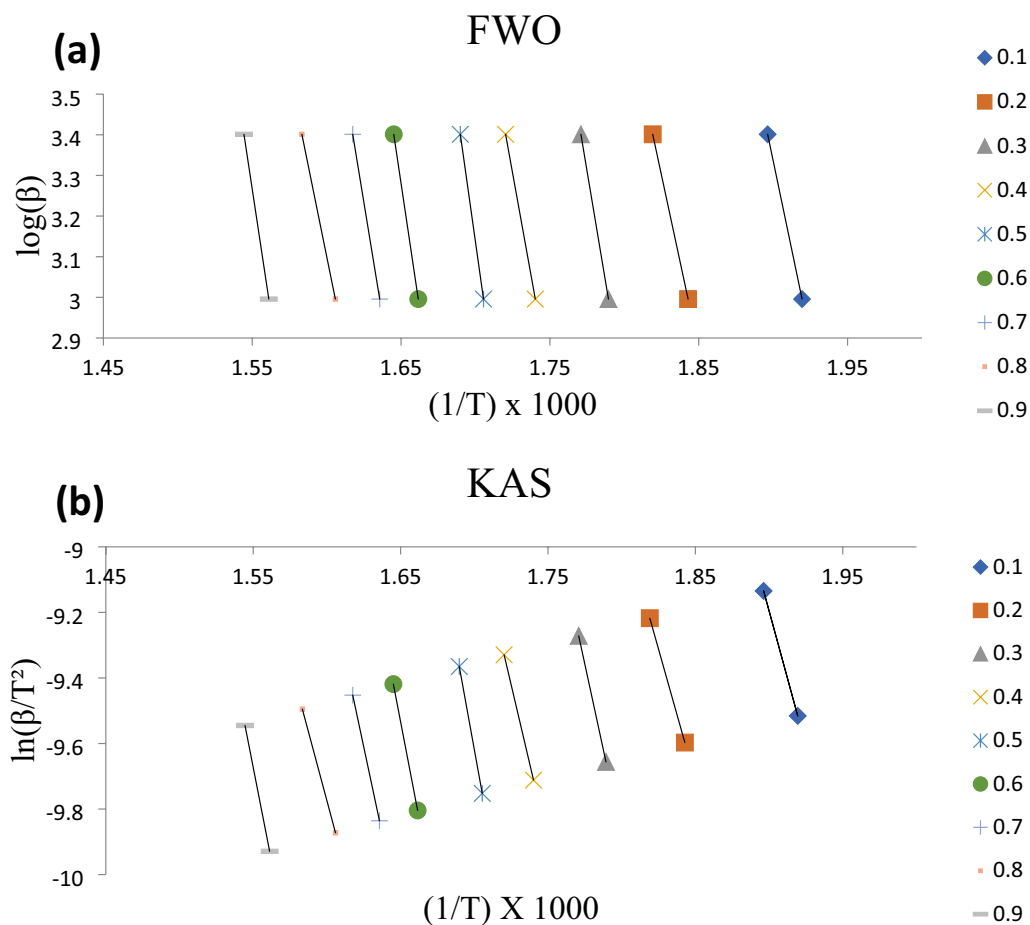


Fig. 7 **a** Linear plots for eucalyptus using FWO method for calculating the activation energy. **b** Linear plots for eucalyptus using KAS method for calculating the activation energy

the range of previously values and this proves that the selected biomasses were best suitable for the thermochemical conversion process to produce the energy for sustainable utilization.

Ash fusion analysis

The AFTs of three raw materials including standard sample given are tested by ash fusion tester are presented in Fig. 8.

From Fig. 8, the ash deformation temperature, softening temperature, hemispherical temperature and flow temperature were 1289 °C, 1342 °C, 1366 °C and 1436 °C, respectively, for standard sample; 1205 °C, 1218 °C, 1222 °C and 1238 °C, respectively, for sawdust; 1506 °C, 1519 °C, 1546 °C and 1580 °C, respectively, for Soyabean;

Table 3 Activation energy and thermodynamic parameters of sawdust

Conversion point(a)	Activation energy	Enthalpy	Gibbs-free energy	Entropy
FWO				
0.1	205.34	200.18	175.47	39.84
0.2	194.05	188.90	175.77	21.17
0.3	131.48	126.32	177.77	−82.97
0.4	209.19	204.03	175.38	46.20
0.5	154.20	149.05	176.95	−44.99
0.6	163.46	158.30	176.65	−29.59
0.7	194.54	189.39	175.75	21.98
0.8	177.59	172.43	176.22	−6.11
0.9	145.84	140.69	177.24	−58.94
Average	175.08	169.92	176.36	−10.38
KAS				
0.1	206.85	201.70	175.44	42.34
0.2	194.69	189.53	175.75	22.23
0.3	128.67	123.51	177.88	−87.68
0.4	210.21	205.06	175.35	47.89
0.5	152.20	147.04	177.02	−48.34
0.6	161.82	156.66	176.70	−32.32
0.7	194.36	189.21	175.76	21.69
0.8	176.36	171.20	176.26	−8.16
0.9	142.78	137.62	177.35	−64.06
Average	174.21	169.06	176.39	−11.82

1465 °C, 1487 °C, 1493 °C and 1500 °C, respectively, for Eucalyptus.

From Fig. 9, the maximum deformation temperature was found in soybean and followed by different selected biomass (Consider the parameter DT, which is more crucial to predicting ash-related problems during biomass conversion than the other three (Fang & Jia, 2012; Li et al., 2018; Li et al., 2021)).

Niu et al. experimented on ash fusion characteristics by ashing the capsicum stalk, cotton stalk and wheat stalk at 400 °C, 600 °C, and 815 °C, respectively, and concluded that the amounts of each element and the obvious ashing temperature do not affect softening temperature (ST), hemispherical temperature (HT), or fluid temperature (FT). As a result, rather than using the ST

as an assessment measure for coal AFC, the DT may be considered instead (Niu et al., 2010). Liu et al. conducted an experiment on ash fusion characteristics of bamboo, wood and coal, resulting in 949.60°C, 1048.20 °C, 1208.40 °C deforming temperatures, respectively (Liu et al., 2018). Li et al., investigated on ash fusion behaviour modification of wheat straw by sludge addition [aluminium plant sludge (APS), paper-making sludge (PMS), and municipal waste-water sludge (MWS)] and results are obtained, as shown in Table 7.

Table 4 Activation energy and thermodynamic parameters of Soybean biomass

Conversion point(a)	Activation energy	Enthalpy	Gibbs-free energy	Entropy
FWO				
0.1	124.61	119.45	178.05	−94.49
0.2	111.39	106.24	178.63	−116.73
0.3	131.01	125.85	177.79	−83.75
0.4	147.12	141.97	177.19	−56.80
0.5	171.51	166.36	176.40	−16.20
0.6	157.26	152.11	176.85	−39.90
0.7	199.99	194.83	175.61	30.99
0.8	209.64	204.49	175.37	46.96
0.9	125.80	120.64	178.00	−92.49
	153.15	147.99	177.10	−46.93
KAS				
0.1	122.28	117.13	178.15	−98.40
0.2	108.18	103.03	178.78	−122.15
0.3	128.53	123.38	177.89	−87.90
0.4	145.25	140.10	177.26	−59.92
0.5	170.72	165.56	176.43	−17.52
0.6	155.60	150.45	176.90	−42.66
0.7	200.34	195.19	175.60	31.58
0.8	210.36	205.20	175.35	48.14
0.9	121.92	116.76	178.16	−99.01
	151.47	146.31	177.17	−49.76

Table 5 Activation energy and thermodynamic parameters of eucalyptus

Conversion point(a)	Activation energy	Enthalpy	Gibbs-free energy	Entropy
FWO				
0.1	138.58	133.42	177.50	−71.08
0.2	134.75	129.60	177.65	−77.48
0.3	173.12	167.96	176.35	−13.54
0.4	160.48	155.32	176.75	−34.54
0.5	205.62	200.47	175.47	40.31
0.6	194.65	189.50	175.75	22.17
0.7	176.77	171.61	176.25	−7.47
0.8	142.51	137.35	177.36	−64.51
0.9	191.81	186.66	175.83	17.47
	168.70	163.54	176.54	−20.96
KAS				
0.1	137.07	131.92	177.56	−73.60
0.2	132.67	127.52	177.73	−80.96
0.3	172.77	167.62	176.36	−14.11
0.4	159.21	154.06	176.79	−36.65
0.5	206.52	201.36	175.44	41.79
0.6	194.71	189.56	175.75	22.27
0.7	175.74	170.59	176.28	−9.18
0.8	139.49	134.34	177.47	−69.55
0.9	191.08	185.92	175.85	16.25
	167.70	162.54	176.58	−22.64

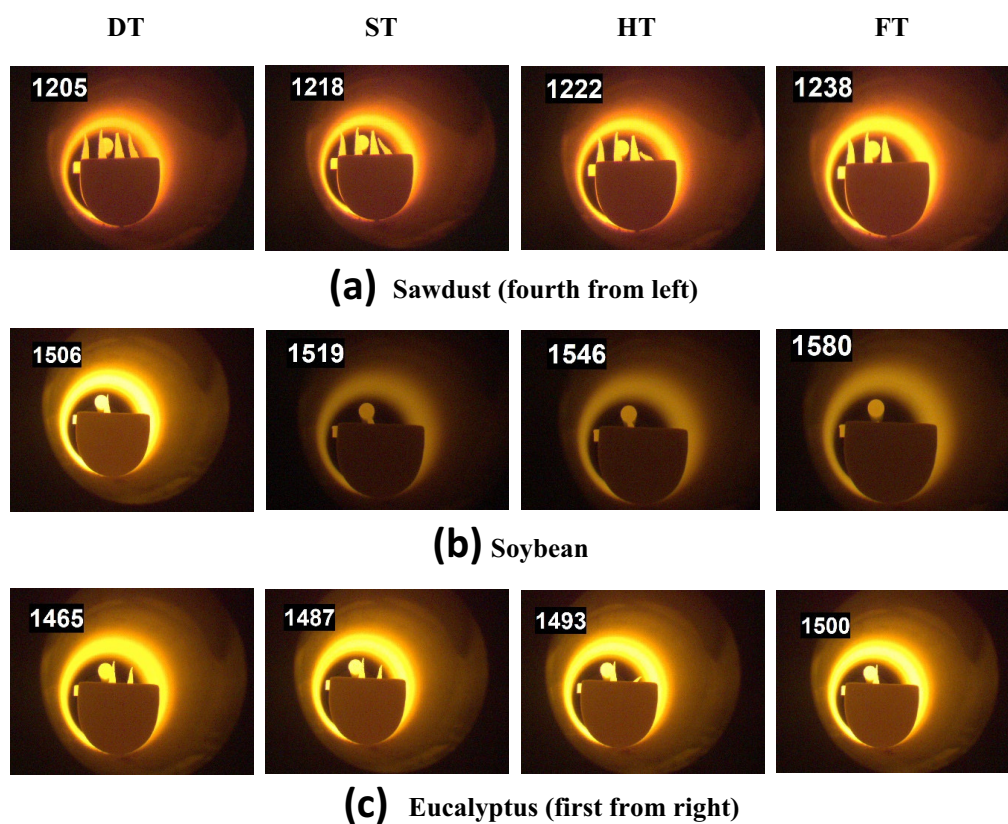
Conclusions

Kinetic analysis of sawdust, soybean & eucalyptus using thermogravimetric under non isothermal conditions was performed at defined heating rates 20 and 30 °C/min of temperature 30 to 900 °C. The minimal difference in enthalpy and activation energy suggests the feasibility of biomass pyrolysis. Drying, devolatilization, and biochar production are the three primary temperature phases in which biomasses thermally decomposes. Flynn–Wall–Ozawa and Kissinger–Akahira–Sunose methods were used to evaluate the kinetic and thermodynamic parameters. Based on iso-conversational approaches such the FWO and KAS models, the activation energy

was calculated, and the average values for sawdust were 175.08, 174.21 kJ/mol, for soybean were 153.15, 151.47 kJ/mol and 168.70, 167.70 kJ/mol for eucalyptus, respectively. AFT was carried out at a temperature range of room temperature to 1600 °C. Among the selected soybean biomass is suitable for co-combustion with coal in thermal power plant. Biomasses with medium melting temperature are used for low load or low furnace temperature boilers. AFT characterization also suitable for various applications like supporting material for methane decomposition for hydrogen production. Further research required to estimate the additives effect on the ash characteristics, alter fusion temperatures, or improve the overall combustion efficiency.

Table 6 Comparison of the thermodynamic and kinetic parameters obtained for sawdust, soybean & eucalyptus to other wood and agricultural residues

Feedstock	Models	Heating rates °C/min	Activation energy KJ/mol	References
Sawdust	FWO, KAS	20 and 30	175.08, 174.21	Present study
Soybean			153.15, 151.47	
Eucalyptus			168.70, 167.70	
Soybean straw	KAS, OFW, Coats–Redfern method	5, 10, 20, and 30	154.15 and 156.22	Huang et al., (2016)
Eucalyptus residues	KAS, starink	10, 20 and 40	159.30 and 160.36	Cai et al., (2016)
Tectona grandis (teak)	FWO, starink	5, 15, 25 and 35	300, 222	Balogun et al., (2014)
Eucalyptus leaves, bark and sawdust	Gaussian DAEM	10 and 40	141.15, 149.21 and 175.79	Chen et al., (2015)

**Fig. 8** Ash fusion temperature of different biomasses (a, b, c)

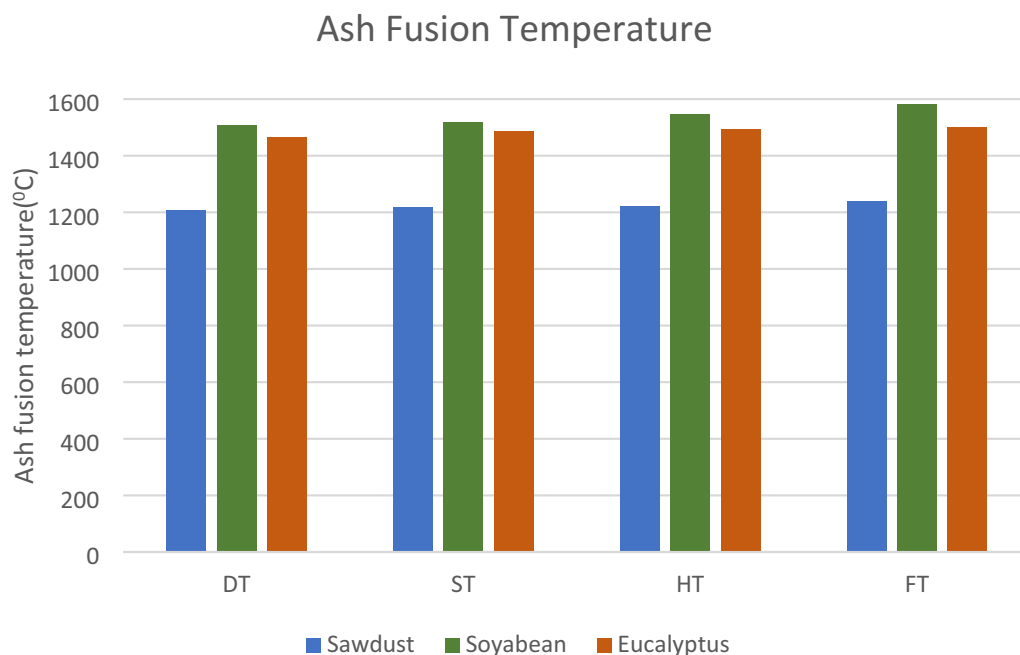


Fig. 9 Comparison of ash fusion temperatures of selected biomasses

Table 7 AFTs of four raw materials

Samples	AFT(°C)			
	DT	ST	HT	FT
WS	890	1013	1089	1121
APS	> 1500	> 1500	> 1500	> 1500
PMS	1152	1278	1392	1448
MWS	1082	1156	1190	1247

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Author contributions

Sachin Channappa Hallad conducted the experiment and prepare the final research paper draft. Kavan Kumar V edited the final manuscript. Dr. N.L. Panwar supervised, reviewed and edited the final manuscript.

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Availability of data and materials

No data sets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

There is no involvement of humans/animals in this particular research.

Consent for publication

This research is concentrating on the utilisation of various biomasses to replace the conventional fuels in the industrial applications.

Competing interests

The authors declare no competing interests.

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