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Bio-Oil Production from Fast Pyrolysis of Hardwood (Padauk) and Softwood (Balsa) Sawdust

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Abstract: *This study investigated the production of bio-oil from hardwood, (Padauk) and softwood, (Balsa) sawdust through the fast pyrolysis process. Fast pyrolysis, a thermochemical decomposition process conducted at 450 – 600 °C in the absence of oxygen, offers a promising route for converting biomass into liquid fuels. The experimental work was carried out using a batch fixed bed stainless steel pyrolysis reactor to examine the effects of key parameters such as reaction temperature, particle size, and sweep gas flow rate (N_2) on bio-oil yield and composition. The bio-oil was characterized using techniques which include Gas Chromatography and Mass Spectrometry (GC-MS), Gas Chromatography - Flame Ionization Detector (GC-FID), Fourier Transform Infrared Spectroscopy (FTIR), and elemental analysis to determine its physicochemical properties such as water content, viscosity, corrosion index, pour and flash points, volatile organic compounds (VOC's), Polyaromatic Hydrocarbon (PAH), and potential as a fuel alternative. Results obtained using response surface methodology (RSM) coupled with a Box-Behnken Design (BBD) showed that optimal conditions for maximum bio-oil yield (63 wt%) was achieved at 500 °C with a sweep gas flow rate (N_2) of 800 mL/min. and sawdust particle size of 0.5 mm coupled with short vapour residence time. Also, from the results of the physiochemical analysis of the bio-oils, the higher flash point, cetane number, iodine value, make hardwood more energy-dense and suitable for high-value applications than softwood but require additional processing to tackle stability issues. Therefore, fast pyrolysis of wood waste (sawdust) can solve part of the rising global demand for alternative energy sources.*

Keywords: Hardwood, Softwood, Fast Pyrolysis, Bio-oil, Sawdust

INTRODUCTION

The move towards renewable sources of energy has largely been due to projections which indicate diminishing reserves of crude oil (fossil oil) on one hand, while predicting increase in the need for energy application on the other hand. The factors contributing to this phenomenon include increasing population and global technological advancement (Isahak *et al.,* 2012). Another justification for exploiting renewable energy resources is that global warming has been linked to the use of fossil fuels through the release of greenhouse gases into the atmosphere. The environmental impacts, limited availability of resources, price fluctuations, and increasing energy demand have given impetus to researchers to explore bio-based chemicals/fuels as an alternative to these non-renewable energy sources.

Biofuels refer to fuels that are obtained from biomass (fuels from living and dead biological materials including agricultural waste, forest residues, sawmill residues, demolition wood, microalgae, municipal waste, and sewage sludge) by various conversion methods. According to Amuitio *et al.* (2012), such fuels have been identified as an alternative energy source to supplement fossil fuel resources. However, in contrast to fossil fuels, the utilization of biomass for energy contributes significant environmental advantages, since organic materials need carbon dioxide for growth. As such, the organic materials remove carbon (IV) oxide (CO_2) that results from biofuel combustion. The bio-based fuel is categorised as "first generation" and "second generation". The first-generation fuel like biodiesel, ethanol, and biogas is obtained from feedstock, such as vegetable oils, residual oils, and fats, while second generation fuel is developed from non-food crops such as lignocellulosic material (Naik *et al., 2010,* Yogalakshmi *et al.,* 2022). Biomass wastes can be converted to biofuels and biochemicals using different technologies including pyrolysis; a process which involves thermal decomposition of the organic polymers (hemicelluloses, cellulose and lignin) found in biomass. This process occurs in an oxygen-free environment and the formation of bio-oil, bio-char and vapour depends on the conditions of the reaction. Pyrolysis can generally be categorized as slow or fast pyrolysis. The slow pyrolysis has been used as an old technology for the production of charcoal (Antal and Gronli, 2003) with oil being a by-product. However, biomass fast pyrolysis is relatively new in application, compared to production of charcoal, combustion and gasification.

Fast pyrolysis of biomass is a rapid thermal decomposition of organic components in the absence of oxygen that converts biomass to organic liquids, solids (char) and gas. It is an endothermic process requiring added heat to be supplied to the biomass to initiate depolymerization at the reaction temperature. According to Bridgwater (2012), any form of solid organic matter can be processed by fast pyrolysis. He indicated that, though most work have been done by many researchers in different countries. The biomass investigated range from agricultural waste, energy crops, forestry waste and municipal wastes. A fast pyrolysis process includes drying the feed to typically less than 10% water in order to minimize the water in the product liquid oil (although up to 15% can be accepted), grinding the feed (to around 2 mm in the case of fluid bed reactors) to give sufficiently small particles to ensure rapid reaction, pyrolysis reaction, separation of solids (char) and collection of the liquid product (bio-oil). Any form of biomass can be considered for fast pyrolysis (Onay and Kockar, 2001).

Fixed bed reactor was used in the bio-oil production from fast pyrolysis of hardwood (Padauk) and softwood (Balsa) sawdust. Fixed-bed reactors can be configured vertically or horizontally, with each configuration impacting bio-oil yield and quality. A study by Onay and Kockar (2003) showed that vertical fixed beds facilitate better vapour flow and produce slightly higher bio-oil yields due to more consistent heat distribution. The addition of an inert carrier gas, such as nitrogen, improves bio-oil yield by reducing vapour residence time and preventing secondary decomposition. Research by Al Arni (2018) found that introducing nitrogen flow in a fixed-bed reactor increased bio-oil yield by 5 – 10%. Bio-oil yields in fixed-bed pyrolysis ranges from 40-60%. Onay and Kockar (2001) reported a maximum yield of around 55% in a fixed-bed reactor under optimal conditions. Fixed-bed bio-oils are rich in phenolics and oxygenated compounds, influenced by slower heating rates and prolonged residence times. Lu *et al.,* (2010) found that fixed-bed bio-oils have higher oxygen content, impacting their energy density and stability compared to bio-oils from more advanced reactor types. In designing a reactor, the main process variables that affect bio-oil yield and characterization are the rate of heat transfer, residence time of vapour and solid particles, temperature, particle size and fast quenching of the vapour. Below is a brief review of the effect of these parameters on the performance of the reactors and the quality of the bio-oil produced. The residence time is the time the pyrolysis gases take to evacuate from the pyrolysis zone to the quenching unit. The residence time detects the degree of secondary cracking reactions. The residence time and the temperature of reaction have strong influence on the chemical constituents of the bio-oil and its physical properties such as density, pH, viscosity, etc. There is extended cracking of pyrolysis volatile vapour when they stay longer in the pyrolysis zone and also when the temperature within the reactor is high.

According to Bridgwater and Peacocke (2000), residence time above 2 seconds results in significant reduction in bio-oil yields. The calorific value is one of the most important characteristics of a fuel, that is the amount of energy per kg it gives off when burnt. Calorific value determines the energy content of a fuel. It is the property of biomass fuel that depends on its chemical composition. Pyrolysis reactors must therefore be designed in such a way as to allow quick and constant transfer of heat to the biomass particle to sustain the endothermic reaction involved in pyrolysis (Adekiigbe, 2012). In order to accomplish high rate of heat transfer for fast pyrolysis, high heat fluxes of 50 W/cm^2 is needed. This condition is unnecessary and difficult to attain in a commercial pyrolysis process. However, low rates of heat transfer encourage the formation of solid products (Yogalakshmi *et al.*, 2022). The effect of heating rate was analysed by Jebdoubt *et al.* (2011), where the rate of temperature change was from 50 °C per minute to 250 °C per minute at a pyrolysis temperature of 550 °C in their work, the amount of bio-oil produced also increased from 45%wt – 69%wt. The Arrhenius law describes the effect of temperature on the rate of a chemical reaction. According to this law, the reaction rate, K increases exponentially with temperature due to the relationship:

$$k = A.exp(\frac{-E_a}{RT}) \tag{1}$$

Where,
K = Reaction rate constant **(s^{-1})**
A = Pre-exponential factor (frequency of collisions that result in a reaction) **(s^{-1})**
E_a = Activation energy of the reaction (J/mol or KJ/mol)
R = Universal gas constant (8.314 J/mol.K)
T = Absolute Temperature (K)

The temperature of the pyrolysis reaction also has a significant effect on bio-oil production. The temperature of the reactor defines the temperature of the pyrolysis process. The processing of biomass from solid to liquid and to gas is influenced significantly by the temperature (Bridgwater, 2012). The bio-oil produced consists of water and organic fractions. The temperature of the reaction determines the quantity of the organic fractions present in the pyrolysis liquid. The organic components during analysis yielded the most at the temperature above 500 °C. More pyrolytic water is produced at higher temperatures which also affects bio-oil quality. The production of bio-char is favoured at low reaction temperature. Pyrolysis temperature affects the structural and physicochemical properties of biochar such as surface area, pore structure, surface functional groups and elemental compositions (Tag *et al.*, 2016). The effect of pyrolysis temperature on such properties can be ascribed to the release of volatiles at high temperature (Sun *et al.*, 2014). Numerous studies reported that high pyrolysis temperature led to increased biochar surface area (Ahmad *et al.*, 2012; Zhang *et al.*, 2015), higher pH (Hossain *et al.*, 2011), %Carbon content but lower %Nitrogen content (Zhang *et al.*, 2017, Sanjib *et al.*, 2020). Thus, the selection of suitable pyrolysis temperature is a compromise between the surface and chemical properties as described. Generally, 500-800 °C is considered as the optimum range for pyrolysis temperature.

The particle size of a biomass has great influence in the pyrolysis process. Large particle size prolongs the residence time of the volatiles which leads to secondary reactions of the volatiles (Sanjib *et al.*, 2020). Large particle size of biomass also exhibits poor ability to conduct heat and a large thermal gradient is formed when particle sizes are large making it difficult for heat to be transferred to the inner parts of the biomass for a rapid pyrolysis reaction. The size of the biomass particles does not affect the yield but rather the quality of the bio-oil (Jahirul *et al.*, 2012) and therefore does not have to be less than 1 mm as reported by other researchers. This assertion is confirmed by Garcia-Perez *et al.* (2008) who reported that biomass particle size influences the quantity of pyrolytic water in the bio-oil. The chemical compositions of biomass feedstock affect significantly the chemistry of pyrolysis process. Generally, lignin, cellulose and hemicellulose are the major components of lignocellulosic biomass (Yogalakshmi *et al.*, 2022).

Hemicellulose is highly susceptible to pyrolysis process and so begins to degrade when heated from temperature of 150 °C to 350 °C (Jinhong *et al.,* 2022) producing primarily non-condensable gases. Cellulose produces char, oil and volatile products when heated above 300 °C (Yogalakshmi *et al.,* 2022). The volatiles produced by pyrolyzing cellulose are condensable. Lignin components decompose at a higher temperature ranging from 250 °C to 500 °C. The heating of lignin produces more solid products. In a comparative analysis of straw, grass and hardwood, Greenhalf *et al.* (2012) observed that the amount of liquid produced increases with higher fixed carbon in the biomass. In their work, Beech wood produced the higher amount of bio-oil followed by switch grass and wheat straw respectively. The moisture content of a solid is expressed as the quantity of water per unit mass of the dry solid. High moisture is a major characteristic of biomass. Thus, high amount of water in the initial feedstock affects the quality of the final products by increasing the quantity of moisture (Asadullah *et al.,* 2008). It also increases the energy demand for the pyrolysis process since water is first removed before decomposition of the biomass starts.

Moisture content of feedstock should not exceed 15 wt% during fast pyrolysis (Dobele *et al.,* 2007). However, feedstock with less than 10% water are recommended. The moisture in bio-oil impacts on the viscosity and density. Density and viscosity of bio-oil decreases when the moisture content increases (Letho *et al.,* 2013). Therefore, the percentage of water in bio-oil varies from 15-35% depending upon the type of feedstock and pyrolysis condition. The water in bio-oil is obtained from the original water content in biomass and during the pyrolysis reaction of biomass such as dehydration and depolymerisation (Yogalakshmi *et al.,* 2022). However, the water in bio-oil possesses advantages and disadvantages such as lowering the viscosity to make it free-flowing liquid and also lowers the heating value and flame temperature, resulting in ignition difficulties, respectively. The bio-oil with high water content can be used in engines or boilers but it requires some modification and circumstances. As regulated in bio-oil norms and standard ASTM D 7544 fast pyrolysis oil (Grade D and G), the maximum permissible water content is 25-30% to use as fuel in the turbine and boiler. Due to the effect of solubilizing compounds present in the bio-oil such as acids, alcohols, ketone and aldehydes make it difficult to separate water from bio-oil (Yang *et al.,* 2015). Generally, the Karl Fischer titration method is used to determine the water content by following ASTM E 203.

MATERIALS AND METHODS

2.1 Materials

The materials used in this study were sawdust (softwood and hardwood) and nitrogen gas. The equipment includes meshed sized operator (0.5 – 2 mm), muffle furnace, analytical weighing balance, centrifuge, measuring cylinder, conical flask, crucible, batch fixed bed stainless steel reactor, heating source (heating mantle), thermocouple, on-off feedback controller (reactor temperature controller), gas cooling system, N_2 gas cylinder and sparger, adjustable condensers together with their appropriate instrumentation and control system and pycnometer.

2.2 Methods

2.2.1 Sample Preparation

In this study, the biomass used were hardwood, Oba Red (Padauk) and softwood, Floater (Balsa) sawdust obtained from Iloabuchi sawmills in Port Harcourt, Rivers State. The samples were dried in the Petrochemical Engineering Department Laboratory of the Rivers State University at room temperature of 27 °C and then sun-dried outside the laboratory for seven hours for each of the two days.

It was further dried in laboratory electric oven at 105 °C overnight (8 hours) to have moisture less than 10% (dry basis) from the initial 35% moisture content (wet basis) in order to have consistent conditions in every experiment and attain constant weight. Later, it was sieved into fractions of particle diameter between 0.5 mm to 2 mm. Prepared samples were weighed and preserved in airtight sample containers for pyrolysis and analysis.

2.2.2 Experimental Procedure

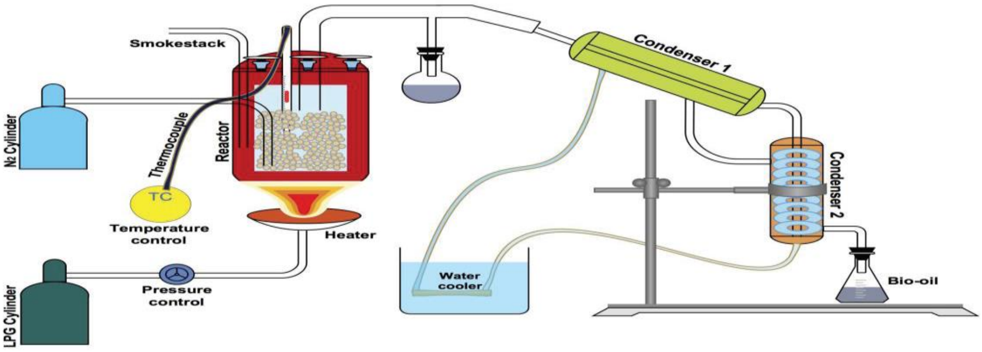

Fig. 1 The Schematic Diagram of the Pyrolysis System

The pyrolysis experiments were conducted in the Petro-Chemical Engineering Department Laboratory of the Rivers State University. The entire process was structured into four functional units; biomass pre-treatment and feeding (including drying and size reduction), pyrolysis of the biomass, product separation and quenching of volatile pyrolysis products to obtain bio-oil. The reaction set-up consists of the following units; batch fixed bed stainless steel reactor, heating mantle (heat source), thermocouple, gas cooling system, N_2 gas cylinder and sparger, and adjustable condenser together with their appropriate instrumentation and control systems. The reactor temperature was controlled using on-off feedback controller. In this work, a vertical laboratory scale fixed bed reactor was deployed and used to perform the pyrolysis experiments. The fixed bed laboratory scale reactor was made of stainless steel and the height and internal diameter are 340 mm and 220 mm respectively. The pyrolysis reactor which has two openings, one opening located on the side of the reactor and the nitrogen gas cylinder was connected using a stainless pipe above the level of the pyrolysis reactor. The reactor was placed in a heating mantle (furnace) with a thermocouple attached to the reactor for temperature reading. Nitrogen gas was utilized as the inert gas and also used to evacuate the volatile products. The flow rate of the nitrogen gas was 10ml/min at the interval of 10 minutes. Once it was 10 minutes, the nitrogen gas flow was stopped while the heating mantle was turned on. The system was designed to process 1000 g per batch of material mass (sawdust).

During the experiment in the bench scaled fixed bed pyrolysis reactor, the feed material (sawdust) was fed into the reactor and tightly covered and heated externally using the heating mantle to pyrolyze the sawdust. The pyrolysis process per batch of 1000 g sawdust took about 1 hour at the reaction temperature of 400 °C – 600 °C when there was no more liquid product condensing from the condensation unit. The condensation unit with a single pass condenser and a round bottom flask with two openings of inlet and outlet valves were used. Nitrogen gas was utilized as the inert gas and also used to evacuate the volatile products (gases and vapours) from the reaction zone, minimizing secondary reactions, thermal cracking and improve bio-oil yield. The condensable fractions of volatile fractions were first condensed in the condenser using water at ambient temperature and further condensed in the round bottom flask. The double cooling was aimed at maximizing the yield of liquid products. After the bio-oil stopped condensing, the heating mantle and the tap were put off.

The bio-oil collector was disconnected from the adjustable condenser and the rector removed from the heating mantle. The resultant products from the pyrolysis reaction; bio-crude and bio-char were collected, weighed and stored in sample bottles for further analysis.

RESULTS AND DISCUSSION

3.1 Results of Laboratory Experiments

Data from the results of the various analyses carried out to evaluate their effects on bio-oil are presented below.

3.1.1 Physicochemical Analysis of Wood

Table-1 Physiochemical Analysis of Wood

Sample	Soft wood	Hard wood
Moisture content (%)	6.48	10.75
Lignin content (%)	33.52	32.19
Bulk density (kg/m^3)	358.74	411.08
Particle size (μm)	525	435
Wood texture	Fine	Very fine

From Table-1, which is the physiochemical analysis of wood, hardwood has more moisture content compared to softwood. This is because hardwood generally has denser cell structures and smaller pores, which helps in the retention of more water while softwood is always less dense and has larger pores that allows quicker water release during drying and this poses as an advantage for bio-oil production. In addition, lower moisture content and lower lignin content in softwood make it suitable for efficient bio-oil production (Bridgwater, 2012). From the same Table-1, it can also be inferred that the lignin content is lower in hardwood as compared to softwood. This implies that softwood has higher potential for producing phenolic compounds during pyrolysis, which are valuable for industrial applications like resins and adhesives (Rowell, 2012). However, hardwood yields lower lignin but higher cellulose-derived products. The comparable lignin content in both softwood and hardwood bio-oil suggest that both produce bio-oils with similar aromatic characteristics. However, the bulk density being higher in hardwood makes hardwood to generate more biomass per unit volume which is advantageous for storage and transportation, and provides greater energy content per unit volume, making it more suitable for combustion-based energy applications (Rowell, 2012). Softwood particles are larger compared to hardwood particles. This is because hardwood fibres are shorter and more fragmented than those of softwood during processing. Smaller particle size in hardwood increases surface area which enhances better heat transfer and faster reaction rates in pyrolysis while larger softwood particles would require additional processing and longer residence times in the reactor (Tabarsa, 2017). Subsequently, smaller particle size and very fine texture of hardwood enhances reactivity but may pose challenges in handling due to higher dust generation while the coarse texture and larger particle size of softwood may result into longer residence times in the reactors for complete conversion. The wood texture is another important variable that enhances bio-oil production. From Table 1, the texture of hardwood is very fine compared to softwood and this makes it to have better compaction and uniformity in processing.

3.1.2 *Bio-oil Physiochemical Analysis Results*

Table-2 Bio-oil Physiochemical Analysis Results

Sample Properties	Softwood Oil	Hardwood Oil	Conventional Diesel
Specific gravity	0.842	0.871	0.82 -0.87
Acid value (mgKOH/100 g)	48.51	60.63	<1
Kinematic viscosity @ 40 °C (mm^2/s)	2.74	2.91	2 – 4
Saponification value (mg/100 g)	195.8	203.2	Not applicable
Iodine value (I_2 g/100 g)	88.10	94.72	< 2
Water content (wt%)	11.36	10.45	< 0.05
Oil content (%)	43.80	51.61	100
Corrosion index	1.34	1.58	Negligible
Pour point (°C)	-13.7	-10.5	-15 to -35
Flash point (°C)	68.2	74.8	> 60
pH	2.8	2.5	6.5 – 7.5
Cetane number	52.86	53.34	40 – 55

Table-2 is the bio-oil physiochemical analysis results. The table showed that hardwood has a slightly higher specific gravity than softwood bio-oil. This inferred that hardwood oil contains more complex or higher molecular weight compounds and also higher energy content per unit volume which is beneficial for fuel applications. This also indicates that hardwood oil is denser than softwood oil, which is being attributed to the differences in the chemical composition and the types of compounds formed during pyrolysis (Rowell, 2012). Subsequently, the hardwood bio-oil result as shown from the table has higher acid value, which implies that it contains more free fatty acids and acidic compounds than softwood bio-oil (Asante, *et al.*, 2023). This higher acid value in hardwood bio-oil implies that it is more corrosive and requires additional treatment such as neutralization before used for industrial applications while lower acid value in softwood bio-oil makes it less corrosive and more suitable for direct applications. From the same Table-2, hardwood bio-oil has slightly higher viscosity than softwood bio-oil which is as a result of its higher specific gravity and more complex chemical makeup, this is supported from the work of Chen *et al.* (2022). However, as it can be seen from the result of the analysis, both hardwood and softwood bio-oils have low viscosity which makes it easier for pumping, atomization, handling and mixing which are the basic bio-oil applications. Furthermore, the saponification value in hardwood bio-oil is higher as compared to the softwood which infers the presence of a greater proportion of triglycerides or ester–like compounds (Liu *et al.*, 2021). The iodine value of hardwood bio-oil is higher than softwood bio-oil, which indicates a higher degree of unsaturation in its compounds. This infers that hardwood bio-oil contains more alkenes or polyunsaturated compounds. Thus, the higher unsaturation in hardwood oil makes it more reactive and prone to polymerization which has negative effect in its storage stability while lower iodine value in softwood makes it more stable and slightly lower reactivity for chemical modification.

Table-2 also showed that softwood bio-oil has higher water content than hardwood which is as a result of the differences in the pyrolysis process or the hygroscopic nature of softwood-derived components (Zhang *et al.*, 2021). This implies that higher water content in softwood oil lowers its energy content and combustion efficiency requiring drying or upgrading while hardwood bio-oil with lower water content is more energy-dense and efficient for combustion.

From Table-2, it can be seen that hardwood bio-oil has a higher oil content which indicates a higher yield of extractable liquid product during pyrolysis. This equally shows that hardwood has denser structure and chemical composition favouring liquid production while softwood bio-oil which has lower oil content requires additional process optimization to increase yield (Li *et al.*, 2022). Hardwood bio-oil has a higher corrosion index as indicated in Table-2, which correlates with its higher acid value and unsaturation thus, making it to be more corrosive for storage and handling of equipment than softwood bio-oil which is less corrosive and more practical for storage and transportation. This is in line with the findings from the work of Chen *et al*. (2022). Therefore, hardwood bio-oil requires corrosion resistant materials and additional treatment to minimize corrosivity. The flash point and pour point of hardwood bio-oil are higher than softwood bio-oil as indicated in Table-2, which implies that it is less volatile and has a lower risk of ignition under standard conditions and also indicate better thermal stability (Wang *et al.*, 2022). This equally enhances safety during storage and transportation while lower flash point and pour point in softwood requires more carefulness in handling (Anil *et al.*, 2019). However, the flash point of softwood and hardwood bio-oils in this work are 68.2 °C and 74.8 °C, which are comparable to 68 °C flash point of Anil *et al.* (2019) and other bio-oils. The cetane number of hardwood bio-oil is slightly higher than softwood bio-oil implying that hardwood bio-oil has more efficient combustion in engine applications while softwood bio-oil with lower cetane number is suitable for biodiesel but may perform less efficiently. The higher properties of hardwood bio-oil from Table-2, such as cetane number, oil content, iodine value, saponification value, acid value and specific gravity make it more energy-dense and suitable for high-value applications but require additional processing to tackle higher corrosivity and stability issues. However, the softwood bio-oil which has lower water content, corrosion index and pour point make it more practical for cold climates and easier handling, though it has slightly lower energy content and thus requires optimization to increase oil yield (Bridgwater, 2012).

From the work generally, it can be inferred that some of the properties (specific gravity, kinematic viscosity, pour and flash points, and cetane number) of bio-oil from both hardwood and softwood fall within the range of conventional diesel which makes bio-oil to be suitable as an alternative energy. Also, from the work of Anil *et al.* (2019), on the elemental composition and physical properties of bio-oil, the pour point, pH, colour and appearance are in line with the results obtained from this work, but the kinematic viscosity @ 40 °C (16.53 mm^2/s) of his work is higher compared to conventional diesel and this study (Morali and Sensöz, 2015).

CONTRIBUTION TO KNOWLEDGE

i. The work offers one of the first comparative analyses of Padauk (hardwood) and Balsa (softwood) sawdust species as feedstocks for bio-oil types in renewable energy systems.
ii. Through the application of Response Surface Methodology (RSM) and Box-Behnken Design (BBD), the study determines optimal pyrolysis conditions (500 °C, 800 mL/min. N_2 flow rate, 0.5 mm particle size), contributing to process design and scale-up knowledge for sawdust-based bio-oil production in sub-Sahara Africa.

iii. The study presents detailed physicochemical data (viscosity, flash point, acid value, iodine value, saponification value, cetane number, corrosion index, etc.) for both softwood and hardwood bio-oils, offering rare benchmark values specific to these wood types and useful for engine compatibility, upgrading, and industrial applications.

iv. The work reveals a critical trade-off; while Padauk (hardwood) yields more energy-dense bio-oil with better cetane number and saponification value, it also presents higher acid and corrosion indices- signaling the need for pretreatment, Balsa (softwood), though lower in yield, produces bio-oil with lower corrosivity and better handling properties, especially in cold environments.

v. The successful use of a simple stainless-steel fixed-bed reactor shows a cost-effective method for bio-oil production and experimentation, promoting local innovation and adoption in academic, or resource-limited contexts.

vi. By valorizing sawdust (a major waste product from the timber industry) into liquid fuels, this work contributes a practical solution for biomass waste management, supporting circular economy practices in the forestry and sawmill sectors.

CONCLUSION

The softwood and hardwood bio-oil physiochemical analysis results showed that both the softwood (0.842) and hardwood (0.871) bio-oil specific gravity fall within the range of conventional diesel (0.82 – 0.87), indicating that they can be blended with diesel without significant issues in fuel density. Although the acid values of both oils (48.51 mgKOH/100 g for softwood and 60.63 mgKOH/100 g) fall within the bio-oil range from literature, but it is higher than diesel (<1) implying that bio-oil is corrosive and require upgrading (hydrodeoxygenation) before use in diesel engines. The results of the analysis show that both bio-oils have high saponification values of 195.8 for softwood and 203.2 for hardwood, which fall within bio-oil range from literature and this suggests the presence of esters and free fatty acids, making them chemically different from diesel as saponification value is not applicable. In comparing the flash points of both bio-oils (68.2 °C for softwood and 74.8 °C for hardwood) and diesel (> 60 °C), both bio-oils have acceptable flash points which is above diesel, meaning that they are safe for storage and handling. While the cetane number for the bio-oils (52.86 for softwood and 53.34 for hardwood) fall within the diesel range of 40 – 55, indicating that they can provide good ignition quality making them potentially viable diesel. However, further processing is required to tackle corroisivity and stability issues. Based on the investigations and analyses covered in this study, conclusion can be drawn that fast pyrolysis of sawdust is a viable and sustainable method for bio-oil production, a possible sustainable source of renewable energy.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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