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Full Length Research Paper

Development and Testing of a Pyrolysis Machine for the Comparative Analysis of Selected Biomass Towards Biofuel Production

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ABSTRACT: Biomass-to-energy conversion (also called bioenergy) covers various biomass forms and origins, conversion options, end-use applications and specifications for utilities. Lignocellulosic biomass may be converted to usable energy products through two distinct pathways: enzymatic or thermochemical conversion. The thermochemical route through Pyrolysis was proposed as a possible bioprocess option for the comparative analysis of Vitex Doniana and Gmelina Arborea (gmelina). This research designed and fabricated a pyrolysis machine used to investigate the physical and chemical properties of two fruit seeds, namely Vitex Doniana and Gmelina Arborea, using the fast pyrolysis method of bio-oil extraction. The prepared materials were pyrolysed in a fixed-bed pyrolysis reactor in the temperature range from 425 to 500 0C. The physicochemical properties and compositions of the feed materials and produced bio-oil were evaluated to quantify their potential for bio-energy use and industrial applications. The measured properties included density, moisture content, ash content, pH, refractive index, cetane index, elemental composition, viscosity, and heating values. Gas Chromatography-Mass Spectrometry (GCMS) and FT-IR spectrum analysis were used to evaluate the bio-oil production from both biomasses. A commercial natural zeolite, namely magnesium carbonate, was used as a catalyst to enhance the oil conversion. Two kilograms of the biomass were loaded into the reactor chamber for the pyrolysis process. The system's primary components are a fixed bed reactor, fractionating cylinder, and liquid condenser. The reactor is heated using an LPG source.

Keywords: Pyrolysis, biomass, reaction chamber, fabrication cylinder, condenser

INTRODUCTION

Oil is the primary driver of global economic growth. Fossil fuels play an important role in the world's overall energy requirements. Energy demand is increasing every day due to the rapid rise of the economy and population (Chukwuneke *et al*., 2019a; Guedes, Luna, and Torres, 2018). The detrimental impact of burning and using fossil fuels for various purposes has generated an environmental risk due to greenhouse gas emissions, climate change, dwindling fossil fuel reserves (Mohamed, 2018), acid rain, and global warming. As a result, there is a greater global search for renewable resources. There has been considerable interest in biomass as a foundation for improving energy sustainability and expanded renewable options. In view of contemporary energy circumstances, biomass holds potential as an eco-friendly, sustainable source of renewable energy accessible across complicated ecological, physical, and thermal processes. It is necessary to obtain biomass (organic material) from trees, agricultural wastes, domestic waste, plantations and factories. As a suitable feedstock for producing liquid fuels soon, biomass holds promise. Hydrocarbon compounds found in biomass may generate fuel-generating heat energy (Tanger et al., 2013). It is against this backdrop that this research was proposed. The *Vitex Doniana (Black Plum)* and *Gmelina Arborea* (gmelina**)** biomass(fruits-seeds) have the biofuel potential. Still, both fruit seeds'

comparative analysis and physicochemical properties have to be evaluated to determine their commercial/industrial capacities and whether they can be converted into useful bioenergy by the pyrolysis process.
The depletion of fossil resources has frightened society in recent years, prompting environmentalists to focus on alternative energies. Their combustion produces a large amount of greenhouse gases, which hurt the environment and reduce the availability of fossil fuels. The fluctuating and rising costs of petroleum oil, the scarcity of fossil fuels, and the negative environmental effects of these fuels highlight the importance of developing a green and environmentally sustainable alternative. Various solutions have been proposed to reduce dependency on fossil fuels and hence reduce greenhouse gas emissions from the atmosphere.

As a result, a pollution-free and environmentally friendly diesel fuel substitute has gained widespread popularity; this replacement offers numerous advantages over conventional fuels. Biofuels have been observed to alleviate environmental consequences due to their efficiency and functional efficiency. To that end, this study will assess the feasibility of employing partially non-edible crops (Vitex Doniana and Gmelina Arborea) for biofuel production while posing no serious threat to food security. The study's primary goal was to design and test a biomass pyrolysis system that uses as little energy as possible.

Objectives

This research was aimed at the following purposes:

To design and fabricate an efficient biomass fast pyrolysis system.
To evaluate the machine performance in carrying out the Pyrolysis of fruit seeds from *Vitex Doniana* and *Gmelina Arborea*.
To conduct the Physico-chemical analysis of the pyrolysed bio-oil from *Vitex Doniana and Gmelina Arborea fruit seeds.*
To carry out the comparative analysis of the physicochemical properties of the two fruit seeds, *Vitex Doniana and Gmelina Arborea*.
To carry out the lifecycle analysis (LCA) of the two plants (*Vitex Doniana and Gmelina Arborea*) selection to determine if the feedstock will be economically and technically viable as a commercial source of biofuel.

Pyrolysis of different biomass

Pyrolysis is the process of converting biomass to liquid (also known as bio-oil or bio-crude), solid, and gaseous fractions by heating it in the absence of air to roughly 500 0C. (McKendry, 2002). The bio-oil can be utilized in engines and turbines, and it is also being investigated as a feedstock for refineries. Because of the various organic waste materials available in societies, energy from pyrolysis will be one of the essential forms of energy that can be produced globally in the future.

Scrap tires are the most frequent organic trash, and their volume is increasing at an alarming rate every year. We researched the behavior and chemical analysis of the pyrolysis oil with I.de Marco Rotriguez. Based on this research, we can conclude that Pyrolysis Oil contains a larger proportion of aromatics and is a complex mixture of organic molecules with 5-20 carbons.

Roy et al. conducted vacuum pyrolysis studies. In this work, he used experiments to develop vacuum pyrolysis of scrap wood. He takes a step-by-step strategy, beginning with bench-scale batch systems and progressing to a process research unit and, finally, a pilot plant.

The percentages of aromatics, aliphatic, nitrogenated chemicals, and benzothiazole are shown by the pyrolysis process's operating temperature. Adrian M. Cunliffe and Paul T. Williams (1998) investigated the composition of oils generated from batch pyrolysis of wastes in a nitrogen-purged static-bed batch reactor using 3 kg of shredded trash at temperatures ranging from 450°C to 600°C. He found that waste pyrolysis produced oil with properties similar to light fuel oil, such as calorific value, sulphur and nitrogen content. He arrived at the conclusion that the yield is 55% oil, 25% carbon black, 9% steel, 5% fiber, and 6% gas.

Isabel de Marco Rodriguez et al. (2001) investigated the chemical analysis and behavior of waste pyrolysis oil. The pyrolysis oil was discovered to have 1.4% sulphur and 0.45 percent nitrogen by mass and to have fuel characteristics similar to other fuels. Polycyclic aromatic hydrocarbons are present in trace amounts in these pyrolysis oils. Polycyclic aromatic hydrocarbons are either mutagenic or carcinogenic in nature.

The oil was analyzed in detail for its polycyclic aromatic hydrocarbon (PAH) content, and a single oil droplet combustion study was carried out. The separated pyrolysis oil had been combusted in an 18.3 kW ceramic-lined, oil-fired, spray burner furnace, 1.6 m in length and 0.5 m internal diameter. And also, an automatic distillation test was carried out at 500 deg. C to analyze the potential use of waste wood pyrolysis oil as petroleum fuels.

Vitex doniana, sometimes known as Black Plum, is a blooming deciduous tree. The black plum (Vitex doniana) is an indigenous fruit tree plant that is vital to the livelihoods of rural communities (Dadjo et al., 2012). It comes from a non-timber forest. Non-timber forest products (NTFPs) are an underutilized resource in many nations (Dadjo et al., 2012). Their potential to boost biofuel production has recently been investigated.

Oil is the primary driver of global economic growth. Fossil fuels play an important role in the world's overall energy requirements. Energy demand is increasing every day due to the rapid rise of the economy and population (Chukwuneke et al., 2019a; Guedes, Luna, and Torres, 2018). The detrimental impact of burning and using fossil

fuels for various purposes has generated an environmental risk due to greenhouse gas emissions, climate change, dwindling fossil fuel reserves (Mohamed, 2018), acid rain, and global warming. As a result, there is a greater global search for renewable resources.

There has been considerable interest in biomass as a foundation for improving energy sustainability and expanded renewable options. In view of contemporary energy circumstances, biomass holds potential as an eco-friendly, sustainable source of renewable energy accessible across complicated ecological, physical, and thermal processes. Biomass (organic material) must be obtained from trees, agricultural waste, home waste, plantations, and factories. Hydrocarbon molecules contained in biomass have the potential to provide fuel-generating heat energy (Tanger, Field, Jahn, DeFoort, and Leach, 2013).

Biomass has promise as a suitable feedstock for the production of liquid fuels in the near future. This research is proposed against this backdrop. The biomass (fruits-seeds) of Vitex Doniana (Black Plum) and Gmelina Arborea (gmelina) have biofuel potential. Nonetheless, neither the comparative analysis nor the physicochemical features of fruit seeds have been studied to establish their commercial/industrial capacity or whether they may be transformed into usable bioenergy via the pyrolysis process.

Physicochemical properties of Vitex Doniana and Gmelina Arborea

The black plum (Vitex doniana) is an indigenous fruit tree plant that is critical to the livelihoods of rural communities (Dadjo et al., 2012). It is a non-timber forest product. Non-timber forest products (NTFPs) are a resource that is underutilized in many nations (Dadjo et al., 2012). In recent years, their potential to boost biofuel production has been investigated.

Vitex doniana, sometimes known as Black Plum, is a tropical African deciduous flowering tree that can reach a height of 20 meters (Dadjo et al., 2012). It features a large, spherical crown. The transparent trunk can grow to be up to 1m across and is covered in pale brown or grey white bark with lengthy fissures and sticky ridges (Dadjo et al., 2012). The leathery, lustrous leaves are opposite and arranged like fingers on a hand, each with five leaflets. Flowers are aromatic and appear in clusters of up to 20 on a tall stalk (Dadjo et al., 2012).

When ripe, the fruit is smooth and oblong, green with white spots, and turns black. The fruits can be eaten fresh or cooked, or they can be converted into jam or wine (Dadjo et al., 2012). The fruits are extensively consumed in northern Nigeria and are virtually always left unpicked throughout farmlands. Gmelina Arborea is a fast-growing tree that grows in a variety of environments and loves wet rich valleys with 750-4500 mm of rainfall. It does not grow well in poorly drained soils and remains stunted; drought frequently confines it to a shrubby shape (Anjaneyulu et al., 1977, 1975). The tree reaches small to overall heights of up to 30 m and has a diameter of 1.2 to 4 m. It has a chlorophyll layer just beneath the outer bark that is pale yellow on the exterior and white on the inside (Anjaneyulu et al., 1977; Kawamura, Ohara, and Nishida, 2004).

The Gmelina Arborea tree is used to make slate frame wood, turnery items, and various sorts of brush backs, brush handles, and toys for chisels, files, saws, screwdrivers, sickles, and other tools (Kawamura et al., 2004). Tea chests, general-purpose plywood, blackboards, frame heart, and flush door shutter cross bands are also made from the wood. Gmelina Arborea leaves are good for cattle (crude protein – 11.9%) and are also fed to eri-silkworm. Gmelina Arborea is propagated through both seeds and vegetative techniques, although despite the fact that the fruit seeds appear delicious, little is done with them. The mature fruits may fall from the tree while they are still green. Green fruits turn yellow after a week, and after about two weeks of dropping, they turn brown and black after approximately three weeks. Because the germination potential of brown and, in particular, black fruits is restricted, it is preferable to pick them when they are still green or yellow.

This study will also design and test a pyrolysis machine for comparing the physicochemical features of biomass and biofuel potential of Vitex Doniana and Gmelina Arborea. Biomass pyrolysis is the heat breakdown of biomass in the absence of oxygen. It is the fundamental chemical reaction that causes all phases of combustion and gasification and occurs naturally in the first two seconds. The components of biomass pyrolysis are biochar, bio-oil, and gases such as methane, hydrogen, carbon monoxide, and carbon dioxide (Salman, 2020).

Pyrolysis is the most common thermo-chemical process. Transformation of biomass wastes into bio-oil and biochar (Chukwuneke et al., 2019b; Mishra and Mohanty, 2020). Rapid Pyrolysis is the heating mechanism of an organic substance (e.g., wood) at high temperatures in the 400-600 C range and rapid reaction time in the absence of an oxidizing agent (Chukwuneke et al., 2019b; Ren, Cai, Du, and Chang, 2017).

Because of the rapid heating, rapid pyrolysis needs small particle size, which informs the essence of the bio-oil created. It is feasible to conclude that pyrolyzing waste materials has a large economic value and may produce a healthier climate (Mazlan, Uemura, Osman, and Yusup, 2015). Bio-oil produced through rapid pyrolysis from sustainable lignocellulosic biomass is the most cost-effective liquid fuel made from organic resources currently (Chukwuneke et al., 2019b; Mazlan et al., 2015).

Pyrolysis-produced Bio-oil is a dark-brown organic liquid with a strong disagreeable odor that, when compared to fossil fuels, contains less hydrogen and carbon but more oxygen (Mazlan et al., 2015). It is an unbalanced but

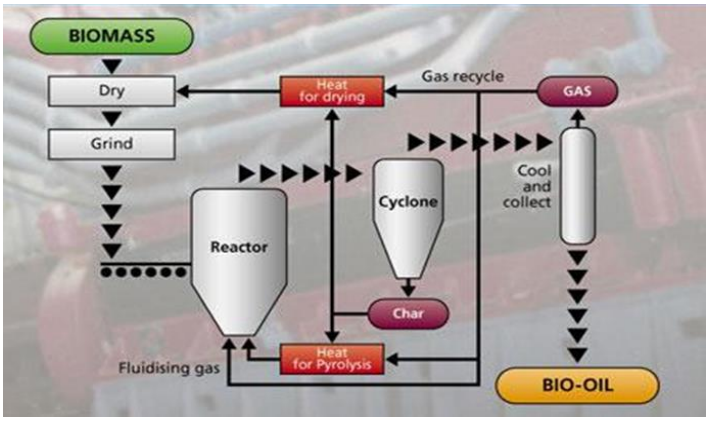

Figure 1: Biomass pyrolysis cycle.

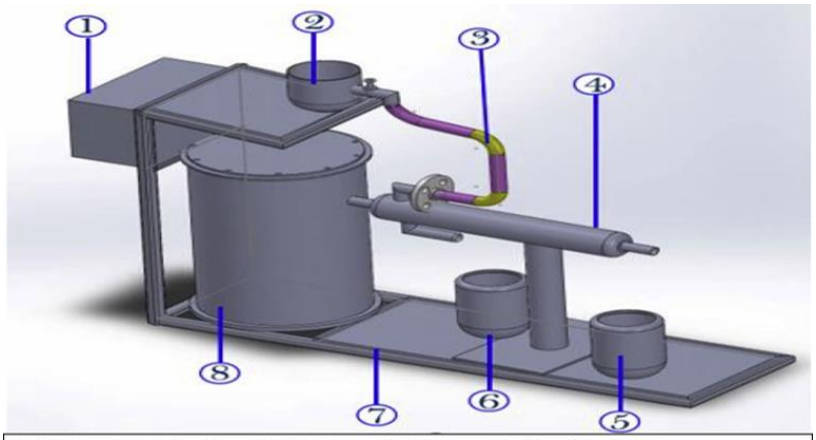

Figure 2: The proposed diagram for the pyrolysis machine.

thermodynamically rich liquid in functional groups. Bio-oil burns quickly in combustion experiments, making it a suitable fuel (Mazlan et al., 2015; Tanger et al., 2013). Depending on the biomass supply, the yields and qualities of pyrolyzed oil will vary (Chukwuneke et al., 2019a; Mazlan et al., 2015).

For this study, bio-oil was extracted from Vitex Doniana and Gmelina Arborea fruit seeds, which are among the most readily available biomass in the Global South, using a rapid pyrolysis technique. The procedure will include the construction and operation of a pyrolysis equipment. By controlling the ignition time and temperature homogeneity, the proposed design and manufacturing (see hypothesized possibilities in (Figures 1 and 2) will influence the success of the pyrolysis process. The process will be carried out at various yield temperatures, followed by a comparison of the fruit-seed products of Vitex Doniana and Gmelina Arborea.

Biomass sample preparation

The Vitex Doniana and Gmelina Arborea fruit-seed samples (Figures 3 and 4) will be obtained from local farms and neighborhoods in Auchi, Edo State, Nigeria. The samples will be sun-dried for 48-72 hours before being pulverized with a hammer mill and sorted with a milling machine to a particle size of less than 1 mm moving mesh 40 (425µm).

Pyrolysis process

Pyrolysis process procedures used are as described by (Chukwuneke et al., 2019a) and represented in (Figure 5). It is anticipated that bio-oil will be produced from Vitex Doniana and Gmelina Arborea fruit seeds (Figures 2 and 3), respectively. Biomass feedstock using the fabricated

Figure 3: *Vitex Doniana* fruit-seeds hanging from a branch

Figure 4: Gmelina Arborea Fruit seeds hanging from a branch.

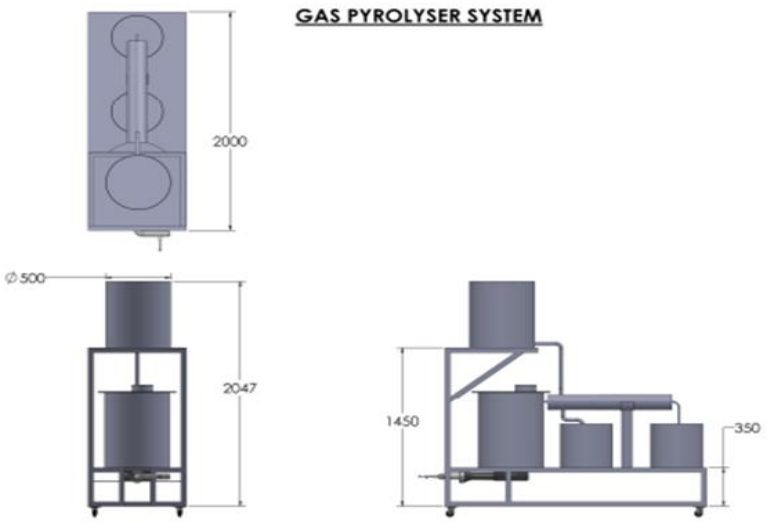

Figure 5: Biomass Pyrolysis System CAD Drawing.

fixed bed reactor pyrolysis system with a capacity of 1 kg/h at the atmospheric pressure, (Figure 1). The pulverized *Vitex Doniana and Gmelina Arborea* fruit seeds will be weighed. 1 kg/h of each sample was heated separately in the pyrolysis reactor by an electric heater at a heating rate of 500 C/s with a pyrolysis product residence time of <1.5s. The temperature will be controlled by an external PID controller and measured by a Ni–Cr–Ni thermocouple fixed inside the bed. The reaction will be executed at temperatures ranging from 425 to 500^{o}C. After that, the bio-oils are to be stored at 4^{o}C in a refrigerator (Guizani, Valin, Billaud, Peyrot, and Salvador, 2017). The ensuing gas from each sample tentatively passed through a condenser to obtain an oil-water mixture which is to be automatically separated into bio-oil and water.

Following that, the physical and chemical attributes of both samples are compared in order to select the crop with the highest bio-oil output, which is then displayed in charts using the R statistical software. The bio-oil can be utilized in engines and turbines, and it is also being investigated as a feedstock for refineries. A lifetime analysis of the products will be performed to determine the environmental impact of their use. Life Cycle Analysis (LCA) is a tool for measuring the environmental impact of a product throughout its life cycle, which includes raw material extraction and processing, manufacturing, delivery, consumption, recycling, and final disposal.

METHODOLOGY

Design of pyrolysis machine

The batch type fixed-bed pyrolysis unit's design and manufacture are essential to this research. The suggested system is created with AUTOCAD and the components shown in Figures 5-7 below. Mild steel, plastic, nichrome (Ni-80%, Cr-20%), stainless steel, k-type thermocouple, leather gasket, and control/instrumentation system are used in the construction. The pyrolysis unit is created depending on system size and cost. It is designed to accept a suitable amount of feed material while maintaining a short vapour residence time in the reactor, promoting a high yield of pyrolysis liquid output.

Maximum time has been spent designing, fabricating, and assembling the experimental setup. The design and fabrication of the fixed bed pyrolysis is the central part of this project work. The fixed bed reactor and condenser are the system's main parts (Figures 2 and 9). The pyrolysis system has been designed based on the following considerations:

- Vapour residence time in the reactor is short.
- Condensation of the vapour product to promote a high yield of pyrolysis liquid product is rapid.
- The heat supply for heating the system has been reliable. Rapid heat rate into the reactor, so it requires less heating material.
- The required amount of pyrolysis liquid that the helping size of the system can produce.

Selection of material and fabrication process

Galvanised iron is utilized due to the corrosive nature of pyrolysis liquid oil created from LDPE plastic and its high operating temperature (350°C to 400˚C). The reactor is done using Oxy-acetylene gas welding to attach the nipple for an airtight chamber utilizing brass as filler metal in the construction. Lathe machines were used to cut the GI pipes. Drilling activities for various GI pipes and clamping holes were performed by the drilling machine. Multiple joints in the stand configuration have been welded using arc welding. The copper coil was chosen as the condenser coil because of its high heat conductivity (398 W/m K) and flexibility.

Barrel/Reactor

The amount of biomass feed primarily depends on selecting the size of the fixed bed reactor. The gas flow rate and reactor volume determine the vapour residence time in the reactor. This vapour residence time is essential in the fast pyrolysis process for maximising liquid products. The residence time should not exceed 5sec for the fast Pyrolysis. A cylindrical reactor has been considered for the system using a galvanised sheet for the ease of fabrication (Figure 5) for the barrel design). Due to pressure development inside the reactor during the heating of Pyrolysis, the reactor act as a pressure vessel. Pressure in the reactor is the sum of atmospheric pressure and pressure due to water in the fractionating column. Only circumferential or hoop stress will be developed because the pressure vessel is an open-end type.

Heating source selection

The heating source must be selected after the reactor geometry has been determined. An LPG gas burner and heating chamber were set. Figure 8 depicts the conceptual design for heating the reactor in the plastic pyrolysis plant. It is possible to gradually raise the reactor's temperature using this system, making it the most efficient for heat transfer. The heat was generated by subsequent mixing and mechanical work, which kept the melt stable.

Design of fractionating column

Pyro-gas consist of light hydrocarbons and tarry substances. It deposits and blocks the connecting pipe

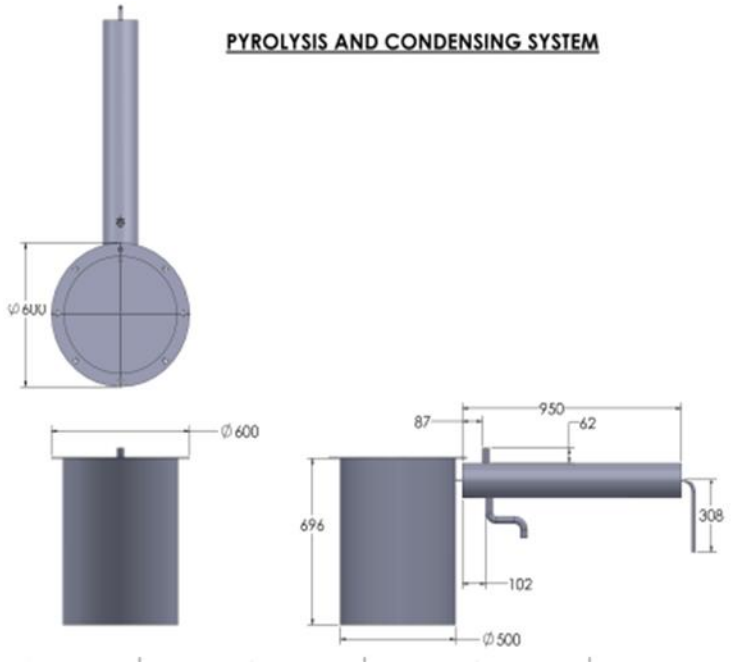

Figure 6: Condenser chamber parts fabricated.

and condensing shell and produces low-grade oil. A separator (a fractionating column) promotes high-grade liquid oil as a partition. The fractionating column is a hollow cylinder. And fractionate cylinder contains water up to 1feet height. For storing the tarry substances during the running time, and they can be collected after completing the run, the inlet port of the fractionating column is at 304 mm height from the bottom flange. A condenser (Figures 2 and 6) is a device or unit used to condense a substance from its gaseous to its liquid state, typically cooling it. The latent heat is given up by the importance and will transfer to the condenser coolant. After separating the heavy compounds in the fractionating column, the pyro-gas flows to the condenser for condensing the formed liquid oil. We have to maintain the constant surface temperature at the outer surface of the copper coil. Heat transfer from the condensing vapour equals heat transfer to the water in the tank. The heat transfer occurs in three steps: de superheating, two-phase forced convection with condensation, and supercooling.

Working principle

The conversion of waste biomass into biofuel is primarily based on the pyrolysis process. Pyrolysis is a thermal decomposition of organic material at elevated temperatures without oxygen. It includes the simultaneous change of physical phase and chemical composition, which is irreversible. The other name for Pyrolysis is thermal cracking, thermolysis, and depolymerisation.

The biomass pyrolysis process is a chemical reaction. This reaction contains breaking down larger molecules into smaller molecules in the presence of heat. At any given temperature, the molecules of the pyrolysis oil are in the vibrating stage. This is called molecular vibration. The molecule's temperature is directly proportional to the frequency of molecules vibrating. During the pyrolysis process, the substance's molecules are subjected to high molecular vibration leading to very high temperatures. At these high molecular vibrations, every molecule in the substance is shaken and stretched so that molecules start breaking down into smaller molecules.

Testing of the machine

The fruit-seed samples from Vitex Doniana and Gmelina Arborea were sourced from local farms and neighbourhoods in Auchi, Edo State, Nigeria. The samples will be sun-dried for approximately 48-72 h, pulverized using a hammer mill and then sifted using a milling machine to a particle size smaller than 1 mm moving mesh 40 (425µm). One thousand grams of dry vitex doniana and Gmelina Arborea seeds were weighed using a weighing balance. The crushed samples were then transferred into the machine to undergo Pyrolysis at a temperature of 400°c for 2 hours. It is anticipated that bio-oil produced from *Vitex Doniana and Gmelina Arborea* fruit seeds (see the figures 6 and 9, respectively) biomass feedstock using the fabricated fixed bed reactor pyrolysis system with a capacity of 1 kg/h at the atmospheric pressure, (Figure 6).

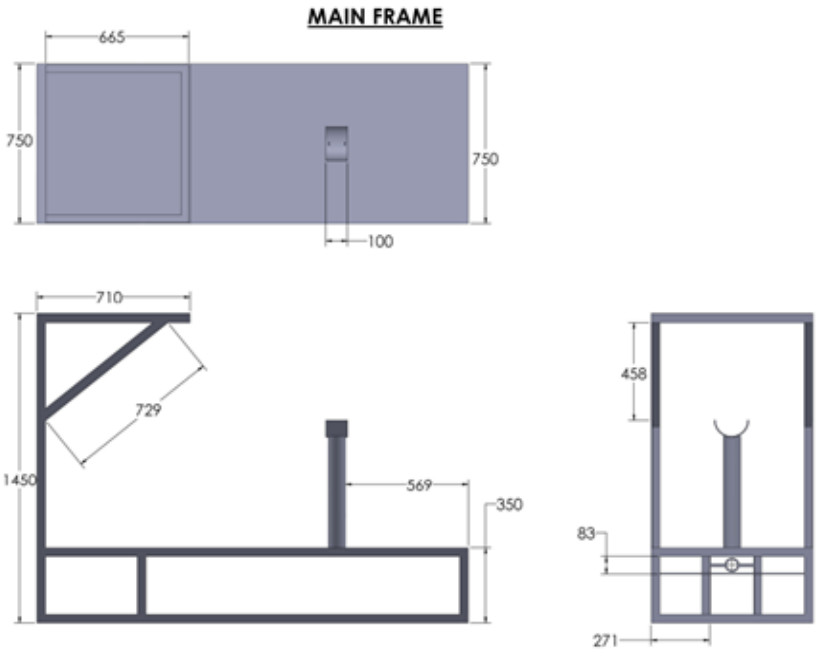

Figure 7: The CAD diagram of the main frame.

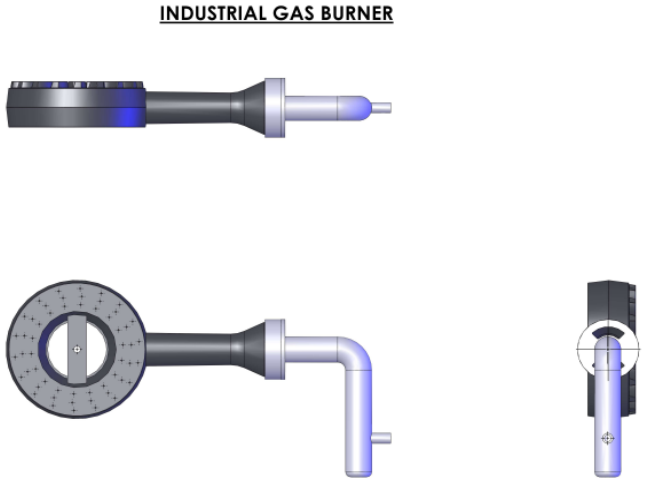

Figure 8: Industrial gas burner as heating source.

The pyrolysis process procedures used are described by (Chukwuneke et al., 2019a) and represented in figure 5. 1 kg/h of each sample is heated separately in the pyrolysis reactor by an electric heater at a heating rate of 500 C/s with a pyrolysis product residence time of <1.5s. The temperature was controlled by an external PID controller and measured by a Ni–Cr–Ni thermocouple fixed inside the bed. The reaction will be carried out at temperatures ranging from 425 to 500 degrees Celsius at 25 degrees Celsius. The gas produced by each sample was tentatively put through a condenser to produce an oil-water mixture that will be automatically sorted into bio-oil and water. Following that, the bio-oils should be kept in a refrigerator at 4oC. (Guizani, Valin, Billaud, Peyrot, and Salvador, 2017). Following that, the physical and chemical attributes of both samples are compared in order to select the crop with the highest bio-oil output, which is then displayed in charts using the R statistical software. The bio-oil can be utilized in engines and turbines, and it is also being investigated as a feedstock for refineries. A lifetime analysis of the products will be performed to determine the environmental impact of their use. Life Cycle Analysis

Figure 9: Side view-photograph of the biomass pyrolysis machine under testing.

Figure 10: Side view-photograph of the biomass pyrolysis machine (trial phase).

(LCA) is a tool for measuring the environmental impact of a product throughout its life cycle, which includes raw material extraction and processing, manufacturing, delivery, consumption, recycling, and final disposal.

Trial phase

A pyrolysis unit is made up of three parts: the reactor or heating chamber, the fractionating cylinder, and the condenser coil. LPG is the fuel used to heat the reactor. The heat input is estimated to be roughly 3kW from a gas system and is given for over 40 minutes. Conduction transfers heat to the biomass reactor through the walls of the heating chamber. MgCO3 acts as a catalyst in the pyrolysis process. To heat the waste biomass, a temperature ranges of 350-4000 C and a pressure of roughly 15 Psi are necessary. To indicate the temperature and pressure, a thermometer and pressure gauge are mounted on the setup. Initially, the pipes' valves will be closed, raising the pressure. The valve will open once there is adequate pressure inside the reactor. The pyrolysis gas from the reactor is then sent to the fractionating cylinder via pipelines and a non-return valve once the valve is opened. 305 mm of water is filled in the fractionating cylinder. The non-return valve prevents the backflow of water. Due to high-pressure gas, the non-return valve opens, and gas will emerge into the water. When pressurized gas comes into direct contact with the water-filled in the fractionated cylinder, some part of the pyrolysis gas condenses and forms a layer over the water, which can be separated. The more volatile amount of the gas goes to the condensing coil surrounded by cold water. The water and gas absorb the heat of the pyrolysis gas in the copper coil and condense into liquid fuel. Which is the final product.

Conclusion

The Pyrolysis system developed here is capable of producing fuel with no operational flaws. Because biomass pyrolysis may produce both liquid and gaseous fuel, it can be utilized to generate energy. As a result, pyrolysis is an advantageous approach for treating waste biomass. A 1kg of waste biomass yields around 200 ml of liquid gaseous fuel. This gaseous fuel can be condensed at low pressure and temperature (-15^{o}C). The volume of the biomass is reduced by around 90%. We determined the calorific value of this fuel by utilizing a bomb calorimeter and the energy's flashpoint. Within 20 minutes of starting, the enthusiasm began to build. Further study should be done to validate the machine's performance.

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