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Production of Bio-Oil in Nigeria: Challenges and Prospects

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A B S T R A C T

The Biofuels Policy and Incentives of Nigeria and the Petroleum Technology Development Fund (PTDF) provide opportunities for converting waste lignocellulosic materials to bio-oil. This paper evaluates the technical challenges that confront the production of bio-oil from locally sourced materials in Nigeria using fast pyrolysis. The paper illustrates fast pyrolysis process; highlighting the different types of reactors available for the process and establishes their comparative advantages and limitations. The design of reactor, workshop for fabrication of equipment, operation, feedstock supply and improving the bio-oil quality and yield, were identified as major constraints to the production of bio-oil locally. This paper concludes that adopting a learning curve approach through research by the design, fabrication, operation and optimization of bench scale pyrolysis systems can serve as a basis to understand and solve the challenges associated with fast pyrolysis such as heat supply and heating rate, char removal, rapid vapour cooling, and vapour residence time.

Introduction

Background

The importance of sustainable alternatives energy development has increased globally in recent years. This has led to several countries; developed and developing, instituting and mandating laws and policies to replace varying proportions of fossil based fuels consumed annually by biofuels.

It is estimated that about 117 billion liters of biofuels was consumed globally in 2013 (REN21, 2014). Although the contribution from Africa is not much, most African countries are thriving to contributing to this effort (Antwi *et al.*, 2010). In 2007, the Renewable Energy Master Plan was launched in Nigeria to provide a framework for increasing renewable energy in the country's energy mix (Popoola *et al.*, 2013).

As a result, it is projected that about 1.3 billion litres of biofuels is needed annually by the year 2020 to achieve its 10 % fossil fuel replacement targets (NNPC, 2007).

Producing biofuels from animal or plant sources (food and non-food crops) is called first generation biofuel. Although first-generation technology is considered mature with many commercial facilities being installed, this is not an option for Nigeria presently since it is a net importer of food (Izah and Ohimain, 2013) and following such a route may lead to food scarcity and insecurity. An alternative is to convert the abundant biomass resources which are generated daily as waste to biofuels. These biofuels are referred to as second generation biofuels. The development of second generation biofuels from lignocellulose sources, such as nonedible plant materials (biomass) has received a lot of attention recently since it provides some advantages over biofuels from food crops (first generation) including including greater reductions in greenhouse gas emissions, reduced land-use requirements, less competition for land, food, fiber, and water, and solving waste disposal problems (Mitchell, 2011; Kemausuor, 2014). It is expected that biomass energy would continue to play a pivotal role in the world's future energy supply (IEA, 2010; Isahak *et al.*, 2012). Already, biomass accounts for about 10 percent of the worlds energy supply (Vakkilainen *et al.*, 2013). This is even higher for developing countries such as Nigeria where biomass supplies about two-thirds of energy services usually through inefficient forms, particularly for cooking and heating (Kuye and Edeh, 2013).

To continue to contribute sustainably to the world's energy demand, biomass must be converted efficiently to forms that can easily be transported and upgraded for several

applications including biofuel and chemicals. Although, this is currently being done in most industrialized and emerging countries on largely pilot basis with a few commercial plants commissioned for continued advancement of the technology, very little is being done in most sub-saharan African (SSA) countries such as Nigeria. These SSA countries have abundant biomass resources and agricultural residue (waste). For instance, there are over two thousand wood mills (wood processing plants) all over Nigeria generating 104,000 m³ of agro-forestry waste daily (Aina, 2006; Iderawumi *et al.*, 2012). The sawdust is heaped and burnt as waste at these wood mills posing environmental and health challenges (Okorie *et al.*, 2015).

The Petroleum Technology Development Fund (PTDF) of Nigeria, as part of its mandate for encouraging the development of indigenous technologies for renewable energy, provides research grants for the production of bio-oil from agro-forestry wastes. Consequently, the PTDF Biofuels research laboratory at the University of Port Harcourt in Nigeria, has since 2012 been studying the conversion of sawdust to bio-oils using fast pyrolysis. The aim of this paper is to highlight some of the technical challenges that confront the production of bio-oil from locally sourced materials in Nigeria using fast pyrolysis. The paper also seeks to give an overview of fast pyrolysis process highlighting the different types of reactors available for the process to establish their comparative advantages and limitations.

Fast Pyrolysis Technology for Producing Bio-oil

Fast pyrolysis is an effective method to convert biomass into liquid products (bio-oil) with yields as high as 75% wt % on wet

basis of feedstock used (Kuye and Edeh, 2013) and has been researched for almost four decades. According to Bridgwater (2012), any form of biomass can be considered for fast pyrolysis and over 100 different biomass types have been tested by many researchers in different countries, ranging from agricultural wastes, energy crops, forestry wastes, and solid and municipal wastes such as sewage sludge and leather wastes.

Also, a large number of organisations are active in research on fast pyrolysis with considerable growth and expansion of activities with more innovation in the types of reactor being investigated. A comprehensive review of existing bio-oil production and research facilities across the world have been compiled as shown in Table.1. Meier *et al.*, (2013) focussed on recent activities in the six member countries of International Energy Agency (IEA) task force of bioenergy activity: Canada, Finland, Germany, UK and USA; while Bridgwater (2012) gave an overview of the activities in other countries in Asia, America, and Europe.

Although, there are few commercial fast pyrolysis plants in the world, the various process technologies are not fully developed (Mictchell, 2011). Hence further studies are required to improve its reliability, performance, product consistency and product characteristics.

A major unit of a bio-oil production system is the reactor. Most research and development has focused on studying and testing bio-oil production with different reactor types using different feedstocks (Bridgwater, 2012) and some of the previous works are summarised in Table.2. The goal is to increase bio-oil yield and quality by optimizing essential reactor characteristics

including; heating rates, heating temperatures, and residence time. Each reactor design has unique performance, product yield capacity, advantages, and limitations. These reactors include fixed beds, bubbling fluidized beds, transported beds, conical spouted beds, cyclones, microwaves, ablative reactors, auger and vacuum reactors. For brevity, the detailed description of these reactors is not included here; however, Table.3 provides a comprehensive comparison of the various reactors.

Meier *et al.*, (2013) outlined the necessary conditions for all reactor configurations to produce high yield of bio-oil from biomass sources using fast pyrolysis as: High heat transfer rates; small particle size of less than 2000 μm ; optimum reaction temperatures of about 500 $^{\circ}\text{C}$; rapid cooling of vapor; short residence time of vapor and char in reactor. However, it has been found that particle size and vapour residence time have little effect on bio-oil yield but rather do affect bio-oil quality (Jahirul *et al.*, 2012).

Technical challenges

There are a number of technical challenges facing the production of bio-oil using fast pyrolysis in Nigeria. These challenges can be categorised as design, fabrication, operational, and analytical challenges.

Fast pyrolysis system design

The appropriate chemical and mechanical engineering design of the various units involved in fast pyrolysis is essential for the efficient conversion of biomass to bio-oil. The detailed designs of these units are however not available in open literature (Isahak *et al.*, 2012) and several studies are currently on-going to fully understand the design of these systems. The high heat

transfer rate that is necessary to heat the particles sufficiently imposes a major design requirement on achieving the high heat fluxes required to match the high heating rates and endothermic pyrolysis reactions. It is reported that faster heating rates at optimum pyrolysis temperature maximize the yield of bio-oil (Chiaramonti *et al.*, 2007; Meier *et al.*, 2013) while low heating rates favour the formation of char ((Wang *et al.*, 2005; Uzun and Sarioglu, 2009). Goyal *et al.*(2008), recommended heating rate of about 300 °C/min for fast pyrolysis.

Reaction temperature

Pyrolysis temperature has a significant influence on pyrolysis products yield, including liquid, gas, and char (Scott *et al.*, 1998; Beis *et al.*, 2002; Kuye and Edeh, 2013). The liquid yields can be divided into organic and reaction water yields. The organic yields reach a maximum at approximately 500°C and further temperature increase results in a reduction of liquid yields. In contrast, reaction water yields rise with an increase in temperature. In the case of gas yields, an increase is observed with rising temperature. The opposite trend is observed with char yields (Aguado *et al.*, 2000; Pattiya, 2011; Bok *et al.*, 2012; Salehi *et al.*, 2013). The increase in temperature enhances secondary cracking of pyrolysis vapours; thus the gas yields increase while the char decreases. Controlling the process to ensure stable optimum reaction temperature is important in maximizing bio-oil yield and quality.

Residence time of volatile products and quenching rate

The design of fast pyrolysis system requires that hot vapours leave the reactor quickly (short residence time) and are rapidly cooled. The time and temperature profile

between formation of pyrolysis vapours and their quenching influences the composition and quality of the liquid product. High temperatures will continue to crack the vapours and the longer the vapours are at higher temperatures, the greater the extent of cracking. Rapid cooling of pyrolysis vapour is still a major challenge in fast pyrolysis.

Char/Ash removal

Char removal is believed to be the most important factor in bio-oil quality and subsequent upgrading processes. These will affect any downstream upgrading of the bio-oil (Bridgwater, 2013). The ash content of biomass has an impact on organic liquid yields through primary and secondary catalytic cracking reactions of the organic vapours. This results in increased water and carbon dioxide and reduced organic yields. Although the total liquid remains about the same, the water content is much higher possibly resulting in phase separation and the heating value is lower due to the higher water content. Therefore, it is imperative to design a fast pyrolysis system to ensure efficient separation of char from the vapour stream before condensation.

Operational challenges

Moisture content of feedstock

High moisture content affects the quality of the final products by increasing the moisture content (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 (Pattiya and Suttibak, 2012). 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 (Bridgwater, 1999).

Table.1 List of some fast pyrolysis systems currently operational
(Bridgwater, 2012; Meier, 2013)

Fast Pyrolysis Reactor	Organisation	Type of activity	Country
Fluid bed	Agritherm,	Industrial	Canada
	Biomass Engineering Ltd	Industrial	UK
	Dynamotive	Industrial	Canada
	RTI	Industrial	Canada
	Adelaide University	Research	Australia
	Aston University	Research	UK
	Cirad	Research	France
	Curtin University	Research	Australia
	ECN	Research	Netherlands
	East China Univ. Science and Technology	Research	China
	Gent University	Research	Belgium
	Guangzou Institute of energy conversion	Research	China
	Harbin Institute of Technology	Research	USA
	Spouted Fluid bed	Ikerlan	Industrial
Anhui University of Science and Technology		Research	China
University of Basque		Research	Spain
Transported (Circulating) Bed	Ensyn	Industrial	Canada
	CPERI	Research	Greece
	Metso/UPM	Industrial	Finland
	Guangzhou Inst. Energy Conversion	Research	China
	University Birmingham	Research	UK
	VTT	Research	Finland
Rotating cone	BTG	Research	Netherlands
Vortex	TNO	Research	Netherlands
Ablative	Aston University	Research	UK
	Institute of Engineering Thermophysics,	Research	Ukraine
	Latvian State Institute,	Research	Latvia
	Technical University Denmark	Research	Denmark
Auger	Abritech,	Industrial	Canada
	KIT (FZK)	Research	Germany
	Mississippi State University	Research	USA
	Michigan State University	Research	USA

Table.2 Summary of some previous works on fast pyrolysis

Feedstock	Pyrolysis	Type of reactor	Yield, wt %	Reference
Cherry seed	Slow	Fixed bed	22	Duman <i>et al.</i> , 2011
Cocoa pod	Slow	Fixed bed	13.8	Ogunjobi and Lajide, 2015
Corn cob	Fast	Fluidized bed	61.6	Mullen <i>et al.</i> , 2010
Furniture sawdust	Fast	Fluidized bed	65.0	Heo <i>et al.</i> , 2010
Grape baggase	Fast	Fixed-bed	27.6	Demiral and Ayan, 2011
Maple	Flash		64.68	Goyal <i>et al.</i> , 2008
Palm fruit bunches	Slow	Fixed bed		Ogunsina, <i>et al.</i> , 2012
Pine wood	Fast	Tubular vacuum	55.0	Ortega <i>et al.</i> , 2011
Pine wood sawdust	Fast	Conical Spouted bed	75.0	Amutio <i>et al.</i> , 2012
Poplar aspen	Flash		71.2	Goyal <i>et al.</i> , 2008
Sugarcane baggase	Fast	Fixed bed	56.0	Islam <i>et al.</i> , 2010
Wood sawdust	Microwave	Microwave	30.0	Miura <i>et al.</i> , 2004
Wood sawdust	Fast	Cyclone reactor	74.0	Lede <i>et al.</i> , 2007
Wood Sawdust	Fast	Fluidized bed	61.7	Salehi <i>et al.</i> , 2013
Yellow corn cob	Slow	Fixed bed	10.2	Ogunjobi and Lajide, 2013

Table.3 Advantages, disadvantages and bio-oil yield of some reactors

Reactor Type	Advantages	Limitations	Oil Yield
Ablative	<ul style="list-style-type: none"> Inert gas is not required 	<ul style="list-style-type: none"> Reactor is costly Low reaction rate 	70%
Auger	<ul style="list-style-type: none"> Compact No carrier gas Lower process temperature 	<ul style="list-style-type: none"> Moving parts in hot zone Heat transfer is suitable for small scale 	30-50%
Bubbling fluidised bed	<ul style="list-style-type: none"> Simple design Easy operation Suitable for large scale 	<ul style="list-style-type: none"> Small particle sizes are needed 	50-65%
Circulating fluidised bed	<ul style="list-style-type: none"> Well-understood technology Good control Large particle sizes can be used 	<ul style="list-style-type: none"> Suitable for small scale Complex hydrodynamics Char is finer 	50-65%
Conical Spouted bed	<ul style="list-style-type: none"> Compact and low cost High heat transfer Short gas residence time 	<ul style="list-style-type: none"> Complex design High impurities in the oil High temperature 	70-75%

		required	
Fixed bed	<ul style="list-style-type: none"> • Simple design • Reliable • Biomass size independent 	<ul style="list-style-type: none"> • Long solid residence time • Difficult to remove char 	35-50%
Microwave	<ul style="list-style-type: none"> • High heating rate • Large size biomass can be processed • Uniform temperature distribution • High temperature 	<ul style="list-style-type: none"> • High electrical power consumption • High operating costs 	30-70%
Rotating Cone	<ul style="list-style-type: none"> • No carrier gas required • Less wear 	<ul style="list-style-type: none"> • Complex process • Small particle • Small scale 	65-75%
Vacuum	<ul style="list-style-type: none"> • Produces clean oil • Can process larger particles of 3-5cm • No carrier gas required • Lower temperature required • Easier liquid condensation 	<ul style="list-style-type: none"> • Slow process • Solid residence time is too high • Require large scale equipment • Poor heat and mass transfer rate • Generates more water 	35-50%

Particle size of biomass

Particle size of biomass feedstock has a major influence on the heating rate, making it an important parameter controlling the rates of drying and primary pyrolysis (Isahak *et al.*, 2012). Jahirul *et al.* (2012) argues that particle size does not affect the yield but rather the quality of the bio-oil and therefore does not have to be less than 1 mm as reported by other researchers. This is consistent with the works of (Garcia-Perez *et al.*, 2008) who reported that, biomass particle size affects pyrolytic water content of the bio-oil. For fluidised bed reactors the particle size can be between 2-6 mm (Jahirul *et al.*, 2012) since further processing will increase cost. Pattiya and Suttibak (2012) recommended that too small particle size range of biomass should be avoided when producing bio-oil from fast pyrolysis, since fine biomass particles tend to be blown or

entrained out of the reaction zone prior to complete pyrolysis. since further processing of feedstock will increase cost. Pattiya and Suttibak (2011) recommended that too small particle size range of biomass should be avoided when producing bio-oil from fast pyrolysis, since fine biomass particles tend to be blown or entrained out of the reaction zone prior to complete pyrolysis.

Fabrication of equipment

Another major challenge apart from the detailed design of the units is the fabrication of the designed units. Once the hurdle of design has been crossed, there is the need to fabricate some parts of the equipment locally to standard specifications. Since fast pyrolysis is an air-tight and high temperature operation, the fabrication of such equipment requires special skills and machines. There

are only few fabrication workshops in Nigeria that have such machines.

Conclusion

Fast pyrolysis bio-oil is an attractive alternative to vegetable oil and animal fat for the production of biofuels in Nigeria. It presents several benefits including waste management to Nigeria where waste treatment is a major challenge. Bio-oil can be produced from virtually any biomass and the fast pyrolysis process for producing bio-oil is relatively new compared to other thermochemical conversion processes. The process can theoretically yield up to 80 %wt of bio-oil from biomass on wet basis.

There are prospects for producing bio-oil from lignocellulosic biomass in Nigeria. There are several technologies including fast pyrolysis which could be domesticated to suit country specific situation. The challenge in Nigeria is that very little work has been done to understand the design, fabrication and operation of fast pyrolysis equipment for the production of bio-oil. The only way to bridge this gap is to build technical capacity by way of applied research. Design, fabrication and operation of bench scale pyrolysis system from first principles can serve as a basis to understand and solve the challenges associated with fast pyrolysis such as heat supply and heating rate, char removal, rapid vapour cooling, and vapour residence time.

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