Technological Challenges & Environmental Mitigation via Bio-oil Production from Biomass Resources

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Abstract. Biomass is among the most promising energy source in the twenty-first century amidst the energy scenario in the global community as a carbon-neutral fuel. Climate change is a global threat to the ecosystem and will be minimized by the introduction of renewable energy into the stream of the world energy projects. This study focuses on drawbacks and prospects of the thermochemical technology such as bubbling fluidized bed, circulating fluidized bed, conical spouted bed, rotary cone, auger and ablative reactors. The challenges are complexities in scale-up of the technologies, sustainability of non-food crop and biomass residues supply, bulkiness and high moisture content, transport network to a centralized storage facility and deoxygenated catalysts development for a higher purity of bio-oil yield and stability. However, the bio-oil yield for BFB, CFB, CSB, RC, A-R and AbR are at an average of 3.52–60, 45.2–75, 9.93–70, 14.27–51.8, 21.7–53.6, 50–70 wt.% respectively. The BFB & CFB are often used, while the AbR shows the highest bio-oil yield. The most promising technology is the AbR with a high propensity of more than 70 wt.% bio-oil yield. Therefore, a techno-economic analysis of the technologies of specific capacity across board be employed for equipment selection, simplified process plant; higher yield with cost-effective operation and maintenance cost etc. Global biodiesel production has been projected from (36 to 39) bln L between 2017-2027 [1] when achieved will go a long way in curtailing the effect of climate change.

Keyword: Ablative, auger, biomass, bio-oil, bubbling, circulating, rotary-cone and spouted-conical reactor.

1. Introduction

The quest for energy has been irresistible as the existence of man, the challenges are to have a cleaner, safer and a cost-effective processes and products. Globally, environmental impact such as greenhouse gas emissions, raise in temperature, ozone layer depletion, health and humanitarian crises etc are, as a result of dependence on fossil fuel. Global emission of SO2 for Africa, Asia, Europe, N/America and S/America are (7.14, 51.73, 19.79, 11.79 & 6.56) million tonnes respectively as at 2010[1]. The annual total CO2 emissions, by world region EU-28, Europe (other), United State, Americas (other), Middle East, Africa, India, China, Asia & Pacific (other), International Transport and Statistical Difference are (3.54, 2.15, 5.27,2.40, 2.67, 1.33, 2.47, 9.84, 5.07, 1.16 and 256.68) billion tonnes respectively[1]. The exploration of renewable energy became imperative to ameliorate those foreseen circumstances. Global ethanol production is projected from (120 to 131) bln L between 2017-2027, while global biodiesel is projected from (36 to 39) bln L between 2017-2027[2]. The elimination of CO2 emissions requires biofuel upgraded technology and innovation, notably for the transport and manufacturing sectors [3]. The European Union (EU) commission proposal the new EU directive (RED II) by 3rd and 4th quarter 2018 for decrease in food-based biofuel from 7% in 2021 to 3.8 % by 2030. Biomass as a promising feedstock because its replenishable, available from farm activities and the only carbon-rich feedstock next to fossils. They are biological and carbon emitted by machineries are reabsorbed by plants making it carbon neutral than fossil fuel [4]. They are cheap and processed into product
fuels (solid, liquid or gaseous) [5]. The process technologies of biomass are subject of concern to maximize return of investment (ROI), better life’s by improving the living standard of humanity. The biomass conversion processes are biochemical, physicochemical and thermochemical, but the safer, timely and cost effective is the thermochemical. Thermochemical conversion processes are robust and flexible in co-firing of feedstocks [6] for energy. The world’s primary energy needed by 2050 has been estimated; biomass generating 15–25% (130–270 EJ/year) with energy crops 20–60% [7]. Researchers are focusing on upgrading the thermochemical technology, as the greatest influence in bio-oil yields is the reactor [8].

The aim of this study is to investigate the technological challenges and possibilities for a Bubbling fluidized bed (BFB), circulating fluidized bed (CFBr), conical spouted bed (CSB), rotary cone (RC), auger reactors (A-R) and ablative (AbR) on biofuel production and air pollution on Eco-system.

2. Technologies in Biomass processing/Reactor processes

Batch, semi-batch or continuous processing of biomass for biofuel were adopted. However, decade of studies revealed worries on batch processes such as high residence time, product variance, high labour cost and complexity in commercial scale up. Researchers had shifted their studies toward a semi-batch and continuous pyrolysis technology for commercialization [9]. The most common thermal pyrolysis technologies are CFBr, BFB, Au & RC reactor technologies etc among the top six (6) to be discussed [10].

2.1. Bubbling Fluidized Bed (BFB) Reactor

BFB reactors are employed widely in pyrolysis for their technological maturity and ability to produce high yield of Bio-oil. Fluidized bed reactor uses a pre-heated gas as heat carrier to fluidize the bed creating homogeneity, short residence times and high heating rates from convection [11]. Four installations based on BFB technology has been constructed by Dynamotive Energy System Corporation, the biggest industry positioned at Guleph with an operation capacity of 200 t d-1. Similarly, researchers at Air Liquide and Karlsruhe Institute of Technology (KIT), German established a biofuel plant feed capacity of 500 kg h-1 with an installed twin-screw mixing pyrolysis auger reactor. The organic and aqueous condensate product can yield up to 55% [12]. Analytical studies of fuel types classified biomass fuels as high in volatiles matter and moisture content, with mineral matters co-rich in alkali and alkaline earth metals such as potassium and calcium [13]. Ash compositions for a wide range of biomass fuels e.g. woody biomass (Ca-, K-rich & Si-lean), herbaceous (Si- & Ca-rich & K-lean) and; rapeseed expeller ash (Ca-, K- & P-rich) [13].

The BFB reactors is scalable, with excellent mass and heat transfer properties, homogeneity and ability to operate continuously etc [14]. However, it shortcomings are sensitive to hydrodynamic conditions, inability to use bed agglomerated feedstocks, high densities bed material with high fluidization velocities and fluidization sweeps gas leads to increased energy input and cost [11]. The Gas output discharge and Bio-oil yield are (Not Mention (NM) & NM, (Atmosphere (ATM) & NM), (ATM & NM), (NM & 3.52wt.%), (ATM & 32wt.%), and (ATM & 60wt.%)) of the system according to [15], [16], [17] and [18] respectively.

2.2. Circulating Fluidized Bed Reactor (CFBr)

The components of CFBr comprised of a riser, a distributor plate, a riser exit, a cyclone, a down comber, a solid feeder, and a butterfly valve [21]. In a CFBr system, particles circulate in the bed. [22]. The CFBr reactors have high heat transfer rate (uniform and effective solids circulation and temperature distribution) [21] effective gas-solids contacting with less gas by-pass, reduced gas-solid back mixing, allows high gas flowrate, negligible intra-particle diffusion resistances and efficient solid regeneration.
capability [23] and; mild reaction conditions and high catalytic efficiency (Wang, L et el.,2018). Nevertheless, it’s pressure drops limitations generally affect design and operation of CFB units for solid fuel conversions. Dense bubbling bed formed at the bottom of the riser, transforming CFB bed to a conventional BFB has been undermine, [24] and the transport dynamics of the sand and biomass is aggressive, which increases the wearing problems.

The Gas output discharge and Bio-oil yield are (re-circulated into the system & 53.2 wt.%), (Not mention (NM) & 78.07 wt.%), (re-circulated into the system & 75wt.%), (ATM & 45.2wt.%) and (re-circulated into the system & 60.65wt.%) of the system according to [25], [26], [9], and [9] respectively.

2.3. Conical Spouted Bed Reactor (CSBr)
CSBR is a fast pyrolysis technology for a residual biomass, even with a heterogeneous composition as alternative to fluidized beds. It as a short residence times suitable for reducing the catalytic activity of the ashes for high bio-oil yields, even for a high ash content material [27]. The CSBR adjudged best for valorisation by fast pyrolysis of multiple wastes, as: sewage sludge, lignocellulosic biomass (pinewood sawdust, forest shrub wastes and rice husk) and other materials, such as tires or plastics. This reactor has also been successfully applied in other thermochemical processes, such as drying, coating, gasification or reforming in CSBR [28].

The merits of CSB reactors are co-pyrolysis, varying particle densities [14], uses high ash content biomass and produce high yield bio-oil [27]., excellent mixing is the spouted-bed design, operating continuous mode and limits to some extent, low residence time and continuous removal of char [28], but excess gas injected into the CSBR invariably hikes the processing cost, scale-up challenge because the ratio of the reactor inlet (20-30) times to the average particle diameter [9], and the continuous mode threshold might affect its scalability [28]. The Gas output discharge and Bio-oil yield are (NM & 70 wt.%), (ATM & (5:1) 9.93 wt.%), (NM & 45.4wt.%) (ATM & 65.8 wt.%) and (NM & 55.8 wt.%) of the system according to [29], [14], [30], [31], and [28] respectively.

2.4. Rotating Cone-Pyrolysis Reactor (RCPPr)
The rotating cone reactor is a novel reactor type for flash pyrolysis of biomass with negligible char formation, with rapid heating and short residence time of the solids can be realised. [33]. The RCPPr development was pioneered at The Twente University, Netherlands in the early 90s, and a 200 kg/h scale-up of the rotating cone was been achieved. The biomass feed and heat carrier sand are injected through the system base, while the centrifugal force displace the solids over the lip of the cone. As the solids spill over the lip of the cone, pyrolysis vapours are directed to a condenser. The char and sand are sent to a combustor where the sand gets re-heated before introducing at the base of the cone with the fresh biomass feed [32].

The merits of RC reactor is about 60% yields demonstrated design on a consistent basis, ease in products recovery. It’s compact in design and does not require a carrier gas for pyrolysis (but it does for sand transport) which makes bio-oil product recovery easier. The transport dynamics of the sand and biomass is not as aggressive as in the CFB process therefore reducing wear problems while the demerits are its complexity integrated process in scale-up, pneumatic transport of sand back to the reactor, lower temperature and longer residence time might set in scale-up. The Gas output discharge and Bio-oil yield are (NM & NM), (NM &14.27%), (recirculated back as heat carrier & 48.3wt.%) (ATM & 47.6 wt.%) and (ATM & 51.8 wt.%) of the system according to [34], [35], [36], [37], and [9] respectively.

2.5. Auger Reactor (A-R)
Auger technology is adapted from the Lurgi process for coal gasification [38]. The main component of biomass feeder is off-the-shelf volumetric screw feeder. Biomass is conveyed using a screw feeder in volumes into the reactor. The auger and heat carrier feeder are calibrated separately, while the feed flowrates are linearly proportional to screw speed [39]. The auger reactor design is suitable for fast
pyrolysis processing, the heat carrier provides enough reaction heat and heat transfer. It holds promise for being a robust system capable of continuous processing with minimal carrier gas compared to other designs. Establishing an industrial scale sized is viable, with minimal operating costs due to minimal gas handling and compression equipment. The auger design may be more compact than other reactor types [38]. Residual carbon increases as high as 20 wt.% of the total char yield and heat carrier attrition of about 7% mass basis after operation for about 2h. Trade-off during heat carrier materials selection may exist for pyrolysis of biomass in an auger reactor [11]. Researches are encouraging in other thermochemical processes in order to justify their operation on the effects on the yield of the bio-oil, char, non-condensable gases, water reaction, heat carrier attrition etc.

The Gas output discharge and Bio-oil yield are (NM & 42.6 wt.%), (ATM &56.3%), (ATM & 23.5wt.%) (ATM & 21.7 wt.%) and (ATM & 25.8 wt.%) of the system according to [38], [40], [41], [11], and [42] respectively. The merits for auger (Au) reactors are operational at a lower heat transfer rate, the ability to convey robust materials, reduced solid particle entrainment in the effluent stream and minimal requirements of sweep gas [11] and it’s operational in forests on-site for bio oil production [43], while the demerit is solids residence time ≤ 120 s required for total conversion and mechanical wear [11].

![Figure 2.5. Schematic of auger reactor system [11].](image1)

![Figure 2.6. Ablative flash-pyrolysis - Experimental Facilities [44].](image2)

2.6. Ablative Fast Pyrolysis Reactor (AFPr)

Ablative Fast pyrolysis (AFPr) technology provides an opportunity to use small particles and large pieces of wood, saving cost of grinding [45] with that AFPr as an advantage over other pyrolysis technologies, possible mobility of AFPr unit for straw upgrade, thereby minimize transport expenses (almost 80% of straw cost are logistic) and also characterized by low construction and operational costs [46].

Relatively, no difference between ablative and fluidized bed reactor of <1 mm particle size, its yield and composition. Except slight difference in yield, HHV, and higher water content resulting from longer vapour residence times in the ablative reactor, which enhances secondary reactions [45]. The Gas output discharge and Bio-oil yield are (NM &70wt.%),(ATM &70wt.%), (ATM & 60wt.%) (NM & 50wt.%) and (NM & 62.1wt.%) of the system according to [44], [44], [46], [45], [47] and [9] respectively. The merits of the AFPr are they operates a vortex reactor with high bio-oil yields [48], characterized by low construction and operational costs [45], uses large particles of biomass and saving processing costs [46] and biooil yield from AFPr are alike to BFB reactor, however, they have complex mechanical design which complicates the scale up. It requires a “gas ejector” to provide extremely high gas velocities and low rate of heat to the reactor rather than the rate of heat absorption by the pyrolyzing biomass.

3. Conclusions

According to [2] the global ethanol and biodiesel production projected from (120 to 131) bln L and (36 to 39) bln L between 2017-2027, will go a long way in curtail the raise in temperature, sea level, and the effect of climate change. Generally, thermochemical technology needs improvement by developing numerical models to optimize the design and operational conditions. The industrial implementation of sustainable supply of non - food crop and biomass residues, biomass densification, moisture content reduction, development of deoxygenated catalysts for conversion of the aqueous phase of the bio-oil to the organic phase to improve its properties or quality, purity, bio-oil yields. BFB, CFB, RC and Ab reactors are prospective large-scale biomass processors, the six reactors realize an arrange of 40 – 75 wt.% bio-oil yield. The promising technology amongst is Ablative with a yield of 50 - > 70wt.% prospect. However, recommending a techno economic analysis to determine the most cost effective and return of investment (ROI) of the thermochemical technology on specified operating capacity.

Acknowledgement
I wish to acknowledge The Petroleum Trust Development Fund (PTDF) for the sponsorship of my research, Abubakar Tafawa Balewa University, Bauchi (ATBU) and the University of Nottingham, Malaysia (UNM).

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