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Assessment of orange peel waste availability in ghana and potential bio-oil yield using fast pyrolysis

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ABSTRACT

The continuous escalation of crude oil prices coupled with declining food supply as a results of the growing global population and climate change have instigated many countries to look out for alternative means of reducing its fossil fuel dependency. In view of this, the study evaluates the available orange peels in Ghana as potential bio-oil producing feedstock using fast pyrolysis technology in order to supplement the country's overriding fuel demand. The paper therefore reviewed the current advancement in fast pyrolysis bio-oil production and utilization, determined the available orange peel produced from fruit processing industries in Ghana and finally determined the potential yield of fast pyrolysis bio-oil to satisfy the projected fuel demand by 2020 and 2030. From this study, Ghana has the ability to replace just about 0.09% of its diesel and petroleum demand in 2020 and 0.07% in 2030 after processing just 10% of the total oranges produced using 2013 orange production as baseline. However, increasing the area of cultivation of oranges to 1.6 million ha (the area covered by cocoa in Ghana) and considering scenarios where the percentage of oranges processed were increased to 40%, 50% and 60% as observed in Brazil, USA, Mexico and other leading producers showed promising potential. The study observed that increasing the area of cultivation of oranges to the same area occupied by cocoa in 2013 saw a possible replacement of total diesel and petrol demand of 8.73% for processing just 10% increasing to 34.92% for 40% processing, 43.65% for 50% processing and 52.38% for 60% processing by 2020. Similarly, in 2030 the country will be able to replace 6.70% of the total diesel and petrol fuels with bio-oil for processing just 10% of its oranges produced which increases to 26.80% for processing 40%, 33.5% for processing 50% and 40.20% for processing 60% of oranges producing. The country still has the potential to channel some of the produced bio-oil for cooking purposes using improved stoves rather than relying on firewood and petroleum fuels. In order to meet these potentials, the study recommended, that the government creates appropriate platform for private sector collaborations and an improvement in R & D in order to integrate the fast pyrolysis technology on large scale.

1. Introduction

Although global production of orange residues is high, the waste has little economic value with reference to its high composition in soluble sugars, cellulose, hemicellulose, pectin and essential oils that could form the basis of several industrial processes [1]. Citrus wastes have been used in producing flavonoid, pectin, fiber and also in producing animal feed [2–6]. Despite these applications, large amount of waste is still generated from citrus annually [7]. For instance, the production of orange juice globally results in residues between 8 and 20 million tons y^{-1}[1]. This biomass could be converted into useful energy. The conversion of biomass waste into useful energy can be achieved through thermochemical and biochemical processes [8]. Bioconversion techniques such as biochemical production of fermentable sugars from the hydrolysate of orange peels and production of methane using biogas technology from the peels are alternative means of utilizing the waste from industrial orange processing in order to avoid problems associated with its disposal. However, the presence of limonene which constitutes about 95% of an orange peel inhibits the activities of fermenting micro-organisms [9–11]. Also, limonene acts as an antimicrobial material which impedes biogas production [12]. Fast pyrolysis as a thermochemical process is one of the most recent renewable energy processes to have been introduced and offers the advantage of liquid product bio oil and now widely studied [13]. The pyrolysis bio-oil can readily be stored and transported, and used as a fuel or in the production chemicals [13,14]. Principally, the yield and composition of pyrolysis products may vary depending on feedstock. Studies conducted on the use of orange waste as feedstock reveal that

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the residue has a higher potential to help curb the over-dependence on fossil based fuels. A comparative study assessing the yield of bio-char and bio-oil in Brazil using elephant grass, straw sugar cane, paddy, coffee husk, and eucalyptus wood, remains of maize, tobacco and orange waste showed that, orange waste and eucalyptus wood gave the highest yield of bio oil and bio char [1]. A similar study conducted by [15,16] obtained appreciable yield of bio- oil. In addition, another comparative study conducted by [17] concluded that pecan nut shell and orange peel are excellent feedstocks for production of energy and value-added products, however, the yield of bio-oil from the orange peel is higher than pecan nut shell. Citrus peel is one of the by-products of fruit processing which provides a great potential for further commercial use [6].

Although biomass already supplies a higher percentage of energy need in developing countries, to large extent, this biomass energy is tapped in an inefficient manner [18]. observed that, approximately 80% of the population of Sub-Saharan Africa relies on wood fuel for cooking and heating. For instance, close to about 90% of Ghanaians rely on wood fuel for cooking and heating [19] and this over-reliance has contributed to a consistent decline in Ghana's forest reserves [20,21]. On the other hand, although oil production has started in the country, projection made by [22] revealed that, the current oil production wells in Ghana could run out by about 2040. The fuel supply in the country is consistently faced with shortages which impede economic development. In view of this, the Energy Commission of Ghana seeks to substitute the national petroleum fuel consumption with 10% biofuel by 2020 and 20% by 2030 [23]. In order to meet this projection, it has been estimated that 336 million liters of biofuel is needed [24]. [25] pointed it out that, an improvement in fuel supply in Ghana using efficient technologies and sustainable feedstocks such as biomass is highly desirable. Based on the prospects seen with the use of orange peels as feedstock for pyrolysis bio-oil production, the paper therefore reviewed the current advancement in fast pyrolysis bio-oil production and utilization, determined the available orange peels produced from fruit processing industries in Ghana and finally determined the potential bio-oil from the available peels to satisfy the projected fuel demand by utilizing fast pyrolysis technology.

2. Global advancement in fast pyrolysis bio-oil production and potential benefits to the overriding energy demand in Ghana

2.1. Characteristics of fast pyrolysis bio-oil

Pyrolysis technology was first used for the production of charcoal more than 5500 years ago in the Middle East and Southern Europe [26]. In ancient Egypt, the technology was also used to caulk boats and in making mummies of human remains [27]. However, early pyrolysis has been faced with slow production, low yield and high amount of air pollutants. The oil crises in 1970 instigated the development of technologies for producing bio-fuels from lignocellulosic biomass [14]. Consequently, advancement in pyrolysis technology has led to the production of bio-oils with some amount of charcoal and gases using fast pyrolysis [28]. In fast pyrolysis, the biomass decomposes very quickly in a reactor to generate high amount of vapors and some little amount of charcoal and gases [1,14,27]. After cooling and condensation of the vapors, a dark brown homogenous mobile liquid is formed which has a heating value about half that of conventional fuel oil. Detailed analysis of bio-oil produced from biomass has proven that pyrolysis bio-oil typically contains more than 400 compounds which have chemical functionalities correlating strongly with feedstock composition and processing conditions [29]. Bio-oils are produced from breakdown of cellulose, hemicellulose, and lignin, which results its the composition [30–32]. Generally, pyrolysis bi-oils usually have densities ranging between 900–1300 kg/m^3[33]. The elemental composition of bio-oil resembles that of biomass rather than that of petroleum oils [14,29]. Table 1 compares the properties of orange peel bio-oil with existing standard from other biomasses and heavy fuels.

Table 1
Properties of bio-oil from orange peel, other biomasses and heavy fuel oil [14,16,33].

Property	Properties of bio-oil from orange peels	Typical properties of bio-oil from biomass	heavy fuel oil
Carbon	46	32–49	85
Hydrogen	6	6.9–8.6	11
Oxygen	46	44–60	1.0
Nitrogen	1.52	0.0–0.2	0.3
Sulphur	0.05	0.0–0.05	N/A
Volatile %, wt	77.11	N/A	N/A
Moisture Content % wt.	15–35	15–30	0.1
HHV (kJ/kg)	18.350	13–18	40.0
Fixed Carbon(% wt)	18.73	N/A	N/A
Ash (%, wt.	4.55	0.004–0.3	0.1
Density (kg/m^3)	1200	1200–1300	N/A
Viscosity(at 50 °C), cP	N/A	13–80	40

**N/A implies that information is not available.*

According to [14], high amount of moisture in biomass feedstock turns to lower the heating value of the bio-oil produced from the biomass. Hence [34] pointed it out that moisture content of the biomass feedstock should be kept less than 10% in order to reduce the moisture content of the bio-oil produced. On the other hand, the viscosity of bio-oil is generally high as compared to diesel fuels. However this can be reduced by the addition of polar solvents such as alcohols. It is widely accepted that the quality of bio-oil from thermal fast pyrolysis cannot be considered a realistic option for large scale liquid transport fuel substitution unless it is upgraded [28].

2.2. Upgrading pyrolysis bio-oil

Fast pyrolysis bio-oil generally has undesired properties such as low heating value, high water content, instability and high level of corrosion as compared to diesel fuel [27,35]. Consequently, attention has been given to upgrading bio-oil in order to attain properties similar to fossil based fuels using various techniques [36–38]. In general, micro-emulsion, catalytic cracking, supercritical fluids extraction, hydro-treating, hydrocracking, steam reforming and chemical extraction have been applied as bio-oil upgrading techniques. A study by [39,40] revealed that, the use of micro-emulsion technology to solubilize bio-oil is one of the promising technologies used to upgrade bio-oil and has the ability to achieve properties closer to that of diesel. In a different study [41], observed that micro-emulsion (using CANMET surfactant) containing 5–30% of bio-oil blended with diesel has the ability to enhance fuel properties such as cetane number, corrosiveness, heating value and heating value. However, bio-oil upgrading techniques have not yet been commercialized due to low biofuel efficiency and their limitations[39]. In general bio-oil processing can be integrated into existing refinery and also blended with petroleum crude [39]. Although none of the bio-oil upgrading techniques have been commercialized, utilization of the various techniques has great potential to improve the properties of the bio-oil.

2.3. Application of bio-oil and potential benefit to Ghana

The commercial fuel demand in Ghana is highly reliant on petroleum and this demand has been growing over time [42]. Although the country currently produces oil, crude oil importation in the country is very high in relation to international trade [43]. The fuel supply in the country is consistently faced with shortages which impedes economic development. According to [44], Ghana's diesel