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Artículo Original

Co-products of *Jatropha curcas* and *Moringa oleifera* as feedstocks for gasification and pyrolysis

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Abstract

Most of the researches over *Jatropha curcas* biodiesel production are focused on fuel properties of Jatropha biodiesel, the approaches and techniques used to produce biodiesel, evaluation of physical, chemical and fuel properties of Jatropha biodiesel and the comparison with biodiesel produced from other feedstocks, or on environmental impact of Jatropha biodiesel or associated with future sustainability of Jatropha biodiesel. Nevertheless, less information can be found based on the potential of Jatropha curcas and *Moringa oleifera* wastes for gasification and pyrolysis. The scope of this paper is to make a state of art survey in this particular subject in order to show the real potential of the co-product of these two biodiesel production feedstocks. The use of the shell and husk by-products of the biodiesel production process from Jatropha curcas and Moringa oleifera is not well reported but there are enough reports demonstrating the feasibility of their use and excellent features as biomass feedstocks for thermochemical conversion. The economic feasibility of small/medium-scale gasification systems integrated to internal combustion engines using JC shell for producing electricity is reported. There is more studies respect the use of JC instead of Moringa. In any case, the implementation of these biomass will depend on disposal, therefore are only suitable in-situ in located specialized agro industrial facilities at local scale.

1. Introduction

Biomass has a current and major interest as a renewable energy source in the context of climate change mitigation and energy security. Energy from biomass is based on short rotation forestry and energy crops that can contribute to the energy needs under the renewability concept.

Most of the researches over *Jatropha curcas* biodiesel production are focused on fuel properties of Jatropha biodiesel, the approaches and techniques used to produce biodiesel, evaluation of physical, chemical and fuel properties of Jatropha biodiesel and the comparison with biodiesel produced from other feedstocks, or on environmental impact of Jatropha biodiesel or associated with future sustainability of Jatropha biodiesel. Nevertheless, less information can be found based on the potential of *Jatropha curcas* and *Moringa oleifera* wastes for gasification and pyrolysis.

Biomass contributes about 15% of the world energy supplies as heat, electricity and fuels for transportation and it is estimated that by 2050, up to 50% of the world's primary energy consumption could be met by biomass [1]. It is well-known that biomass consists mainly of three major components (hemicellulose, cellulose, and lignin) together with trace of extractives and minerals. Normally, cellulose, hemicellulose, and lignin cover 40-60, 20-40, and 10-25 wt.% of biomass on dry basis [2].

The conventional raw feedstocks for biodiesel production usually are coming from edible oils, such as palm, soybean, sunflower and rapeseed oils. A challenge for biodiesel production is to use feedstocks that would not compete with human food stocks. In that direction, *Jatropha curcas* (JC) has been identified among the most promising non-edible oil for biodiesel production. Jatropha produces mainly non-edible oil due to the phorbol esters that are toxic, even at low concentration, although there few species of Jatropha that produce edible oils. The seeds of JC are generally used as fuel and resource. Beside biodiesel production, the plant has other purposes too. The seed cake can be used as fertilizer, as a fuel for combustion, and in biogas production and charcoal production. The plant itself has medicinal value, and is also used for erosion control. The seed yield is considered to be 0.3 to 1.5 dry tons per year, whereas the oil content of the seed is about 40% of the mass. Oil yield after the processing is about 25% of mass of the seed input and the energy content is about 37 MJ/kg of the seed [3].

Jatropha curcas is native of tropical America, has been later introduced into Africa and Asia and is now cultivated worldwide [3]. Jatropha is a genus of approximately 175-200 plants, shrubs and trees, from the family of Euphorbiaceae. It is resistant to drought and produces seeds containing up to 40% mass of oil. When the seeds are crushed and processed. Jatropha species show some differences among them, mainly in the chemical composition, and influenced by climate and agro industrial harvesting conditions [4]. A number of Asian countries are projected to produce large amounts of Jatropha curcas: China 19,050,000 (tons of JC oil in 2017); India 16,750,000; Indonesia 6,570,000; Myanmar 4,250,000; Thailand 300,000; Philippines 18,000; Malaysia 8000; Cambodia 2000; Nepal 2000 [5]. About 17-18% of *Jatropha curcas* oil is extracted using mechanical expeller from the seed and the remaining cake is treated as a waste [6]. The oil production from Jatropha seed results in a by-product of 2.5-3 ton of de-oiled cake per ton of biodiesel.

On the other hand, Moringa is a small genus for a mono-generic family called Moringaceae. It includes thirteen species of shrubs and trees originating in Asia and Africa that have been distributed in many other tropics lately [7, 8]. *Moringa oleifera* (MO) has been investigated due to its fast growth, apparent nutritional attributes, and utilization as a livestock fodder crop. Its seeds both contain a good-quality vegetable oil, and can be used as a coagulant to replace conventional coagulants in drinking water treatment. It can be grown on marginal lands and low water availability [9, 10]. Moringa has high biomass yield over time with up to 24 tons ha per (on dry basis). The major task is the oil extraction of Moringa. In this respect a well-known basic procedure is followed as represented in Figure 1. This process is quite similar to the oil extraction of Jatropha curcas. From the expeller machine, Jatropha kernels emerge, along with a by-product (shells of husk). The kernels are sent to an extraction process, which produces crude oil and another by-product called oil cake seed. The oil content in Moringa species is between 38-42 wt.% [7]. The rest are co-products or waste. Most of the last are the seed husk and the seed oil cake.

Both may be considered as energy sources. Mainly, they can be burned to produce heat [5]. The gasification of the shell seems more advantageous than other methods of energy conversion. However, there has been lack of reports focused on the subjects of gasification and pyrolysis of these co-products derived from Moringa and Jatropha oil extraction industry.

High moisture and ash contents have negative impact on the combustion or biomass conversion process. Both reduce the heating content of the biomass. Moisture also reduces the combustion temperature. Generally, the ash content in biomass varies from 10-40% and high ash content (>10%) leads to slag deposition on the bottom of the furnace [7]. In both cases, these co-products of biomass carry ash contents lower than this warning limit. Concerning the volatile matter content, it has a positive impact on the thermochemical conversion if the production of bio-oil or syngas are the task [11]. Nevertheless, the moisture and ash contents may be strongly influenced by soil properties and cli-mate conditions under which they grow.

Moringa and Jatropha seed husk were found to contain small amounts of N and S (<1%), reducing the possibility of NO_x and SO_2 emissions to the environment. On the other hand, *Jatropha curcas* has a ratio content of cellulose, hemicellulose and lignin of 56:18:24 [12]. Jatropha husk is found to be a sustainable precursor of activated carbon production [13]. JC seed shell has 37:5:40 [14]. Ash content in feedstocks over 17% is reported to reduce the H_2, CO production and the higher heating value (HHV) of the biofuel produced [15].

The scope of this paper is to make a state of art survey in this particular subject in order to show the real potential of the co-product of these two biodiesel production feedstocks.

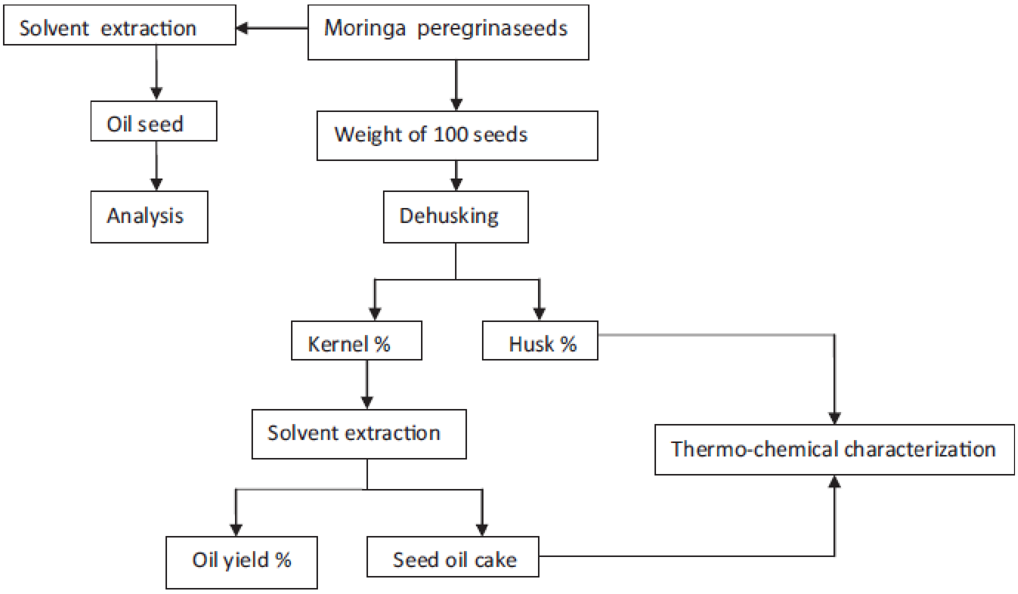

Fig.1 Procedure of oil extraction for Moringa and Jatropha curcas

2. Gasification and pyrolysis of *Jatropha curcas* and *Moringa oleifera* co-products

Gasification is a thermochemical process that converts carbonaceous materials into H_2, CO, CO_2, and CH_4 with the inclusion of a gasification agent and catalyst. It is a very flexible technology which can be adapted to treat a myriad of materials, and the process conditions can be altered to selectively isolate different gaseous products [15].

Pyrolysis is a thermochemical process that is an efficient way of converting biomass into liquids (bio-oil) with gases and char at temperature as relatively low as 300-600ºC. In particular, fast pyrolysis process of biomass materials is effective for raising liquid product yield. In order to raise liquid product yields in the pyrolysis, parameters such as temperature, heating rate, residence time, pressure, and catalyst, biomass type and characteristics (particle size, shape, and structure), are extremely important [16]. Bio-oil can be directly applied in boilers, industrial kilns, slow-speed diesel engines and gas turbines [17].

For different gasifier types, different biomass parameters are required. Concerning moisture content, up to 60 wt.% are feasible for using in updraft gasifiers, between 5 and 60 wt.% in circulating fluidized bed and between 10 and 25 wt.% in downdraft gasifiers [18]. According to the moisture content reported for all feedstocks shown in Table 1, all are suitable for gasification. Concerning the ash content (db), updraft and circulating fluidized bed less than 25% is required while less than 6% for downdraft [18]. It is clear from Table 1 the suitability of all feedstocks for updraft and circulating fluidized bed technology.

Table 1. Comparison of parameters related to the potential of biomass of Moringa oleifera and Jatropha curcas

Parameter (%)	JC seed husk	JC seed oil cake	MO seed oil cake
Moisture (db)	6.8-13.4 [19-21]	8.3 [22]	10.4 [22]
Volatile matter (db)	64.9-82.2 [19-21]	72-88.3 [22, 23]	75.1 [22]
Ash (db)	3.9-5.8 [19-21]	4.6-6.5 [22, 23]	6.3 [22]
C (dbea)	49-50.9 [19, 20]	44.4-57.7 [22, 23]	45.6 [22]
H (dbea)	5.8-6.3 [19, 20]	6.2-7.7 [22, 23]	6.3 [22]
O(dbea)	39 [19, 20]	26.6-44.5 [22, 23]	41.4 [22]
N (dbea)	0.8 [19]	3.2-4.3 [22, 23]	6.5 [22]
S (dbea)	0.08-1.1 [19, 20]	0.2-0.5 [22, 23]	0
HHV (MJ/kg)	16.7-18 [19, 21]	18.1-24.4 [22, 23]	20.5 [22]

db-dry basis; dbea-dry basis excluding ash content

The amount of solid residues in the case of Jatropha cake is varied from 11.44% to 26.72% in a downdraft gasifier [24]. The utilization of waste biomass originating from Jatropha processing is proved as suitable for reusing of Jatropha waste biomass as a feedstock for briquette production [23, 25, 26]. Some of reports found in literature concerning thermochemical conversion of these two biomasses are presented in Table 2

Table 2. Gasification and pyrolysis applied to Jatropha curcas co-products

Feedstock	Thermal process	Reactor	Experimental conditions	Target	Product characteristics	Reference
Moringa oleifera seed husk	Single stage steam pyrolysis	Carbolite 12/65 tube furnace	Charges of 30 g heated at 20°C/min. 800°C for 30 min.	Carbon production	Highly microporous activated carbon, with surface areas of 549-931 m^2/g	[27]
Jatropha curcas seed husk	Fast pyrolysis	Single-shot microfurnace pyrolyzer (PY-2020iD) with autosampler and coupled to GC-MS. (updraft). Heating rate: 1000ºC/min	Sieved to 125 mm and oven dried for 24 h at 383 K. AC support impregnated with ($Ce(NO_3)_3 \cdot 6H_2O$, $Pd(NO_3)_2$, $Cl_3Ru \cdot xH_2O$ and $Ni(NO_3)_2 \cdot 6H_2O$)	Bio-oil	Upgraded bio-oil	[20]
Jatropha curcas seed oil cake	Fast pyrolysis	PY-2020iS pyrolyzer coupled to GC-MS	Ni-modified zeolite catalyst	Bio-oil	50% yield. Acid value of 1.99 mg-KOH/kg	[16]
Jatropha curcas seed husk	Gasification	ND	Simulated by ASPEN Plus	Hydrogen production	H_2 (27-36%) CO_2 (5-29%) CH_4 (0.5-10%)	[5]
Jatropha curcas seed husk	Fast pyrolysis	Single-shot microfurnace pyrolyzer (PY-2020iD) with an autosampler and coupled to GC-MS.	Zeolites as catalysts	Hydrocarbons and gas	Gas phase (30-38%) HC (43-51%)	[28]
Jatropha curcas seed oil cake	Pyrolysis	fixed-bed pyrolysis	Pyrolysed over (573-1073.15 K). N_2 at $7.8 \cdot 10^{-5}$ m/s to $6.7 \cdot 10^{-2}$ m/s	Bio-oil	50% of the waste is cracked down into bio-oil, with less than 30% water content, 15.12 MJ/kg and pH of 6.77.	[29]
Jatropha curcas seed oil cake	Pyrolysis	Batch pressure reactor (Series 4580 HP/HT Reactors, Parr Instrument)	Maximum pyrolysis gas yield at 600ºC with the energy content of 4.2 MJ/kg. Pyrolysis at 500ºC was optimum	Bio-oil, biochar and gas	Biochar (37-44%) bio-oil (24-27%) gas (13-21%)	[30]

			condition with 89% of mass conversion and 77% of energy recovery.			
Jatropha curcas wastes	Fast pyrolysis	Pyroprobe pyrolyser (multifuntional pyrolyzer, PY-2020iD Frontier Lab)	catalyst ratio of 1:5 optimal for enhancing aliphatic hydrocarbon production	hydrocarbon production	Ni/CaO showed the highest hydrocarbon selectivity (47.5%) at a 1:5 biomass: catalyst ratio	[17]
Jatropha curcas seed oil cake	Flash pyrolysis	Electrical heated fluidized bed reactor	Sample fed at 30 g/min Gas flow rates of 1.25-2.4 m^3/h 350-550ºC of pyrolysis temp.	Bio-oil	Maximum oil yield of 64.25wt.% Calorific value of bio-oil: 19.66MJ/kg.	[31]
Jatropha curcas wastes	Fast pyrolysis	PY-2020iS pyrolyser (Frontier Lab) connected to GC-MS	Samples of 0.4 mg rapidly pyrolysed at 550ºC	Hydrocarbons focused on aromatics	Using zeolite catalyst, aromatic compounds were formed above 90% of the obtained organic products.	[32]
Jatropha curcas seed oil cake	Fast pyrolysis	Fluidized bed reactor (0.102 m id. and 0.97 m high)	Pyrolysis conducted at 380-530ºC with N_2 flow rates of 15-41 L/min at 25ºC. Biomass particles (average size=0.7 mm) fed at 0.94 kg/h	Bio-oil, biochar and gas	27.2% of liquid oil (oil phase), 20.6% of liquid oil (water phase), 24.4% of gas and 27.8% of char	[33]
Jatropha curcas seed oil cake	Fast pyrolysis	Catalytic fixed bed reactor. quartz tube of 4.2 m length with internal diameter of 50 mm, electrically heated	Catalyst: Na_2CO_3supported γ-Al_2O_3.	Bio-oil	Bio-oil with very low oxygen content, water content of 1wt.%, neutral pH, and calorific value of 41.8 MJ/kg.	[34]
Jatropha curcas seed oil cake	Fast pyrolysis	Fixed bed tubular reactor with carbolite tubular furnace type CTF 12/100/900	heating rate of 25.6 K/s	Bio-oil	At optimum conditions for the fast pyrolysis (temp. of 747.15 K and N_2 linear velocity of 0.0078 cm/s),	[35]

					40.93 wt.% of biomass was converted into bio-oil with 16.92 MJ/kg, water content of 28.02 wt.% and pH of 7.01	
Jatropha curcas seed oil cake blended with bituminous coal (1:1)	Pyrolysis	SS316 fixed bed tubular reactor	A batch of 100 g increasing the pyrolyzer temperature from ambient to 550ºC at 5ºC min/min and finally kept constant for 30 min	Bio-oil	13% of CH_4 in the gases 29.5% of organic oil phase and 27.7% in aqueous phase	[36]
Jatropha curcas seed oil cake	Fast pyrolysis	pyroprobe (multifunctional pyrolyzer, PY-2020iD, Frontier Lab) with GC-MS	Al_2O_3, ZrO_2 based catalysts	Bio-oil	fatty acid (palmitic acid, oleic acid and acetic acid) which carboxylic acid of 41.11-63.86%.	[37]

Murata et al. developed two researches focused on the pyrolysis of Jatropha curcas wastes [16, 32]. Both works were addressed to the catalyzer's assessment, based on Ni and microporous materials (zeolites), using Jatropha residues as feedstocks. They report that when Jatropha residues (50 g) were used with NiMo(O)/Y at 500ºC, the total liquid yield was 49.9%, including 21.3% of organic liquid. Ni-based catalysts such as NiMo(O)/Y were found to be effective and comparable to PtPd/ZSM. On the other hand, Murata [32] also studied the decomposition behaviour of Jatropha wastes by pyrolysis (husk, seed shell and branch) in order to obtain liquid organic compounds. In the absence of catalyst, the Py-GC/MS analyses for pyrolysis of Jatropha wastes show a range of aromatic hydrocarbons, phenols, alcohols and ketones, acids and esters, ethers and aldehydes. Aromatics are predominantly formed above 90% of area percentage by use of catalyst. Of aromatic compounds, xylenes, naphthalenes and toluene are mainly produced. The product selectivity is dependent on both the size of the catalyst pores and the nature of the active sites and one candidate is H-ZSM-5 and the other candidate is β-zeolite.

Mochizuki et al. [28] developed a zeolite catalyzed fast pyrolysis of the *Jatropha curcas* husk and compared it with cedar biomass at 300-600ºC in order to elucidate the effect of thermal decomposition. The lignin concentration in Jatropha husk (20.2 wt.%) was lower than that in cedar. The amount of ash formed by the pyrolysis of Jatropha husk (20.7 wt.%) was clearly greater than that formed by the pyrolysis of cedar (0.6 wt.%). They found that the ash of the Jatropha husk was made up almost exclusively of K (85.6 wt.%) and Mg (8.5 wt.%). The authors developed a study of fast pyrolysis with and without catalyzer.

The formation of furfural and 2-hydroxy-2-cyclopenten-1-one, which were derived from cellulose, was the highest in the case of cedar at 400ºC and at 350ºC in the case of Jatropha husk. On the other hand, the formation of guaiacol and 2-methoxy-4-vinylphenol, which were derived from lignin, was the highest at temperatures of 450-500ºC in the case of cedar and at 500-550ºC in the case of Jatropha husk. These results suggested that Jatropha husk was easier to pyrolyze than cedar. In particular, aromatic hydrocarbons were produced in a large amount during the pyrolysis of the Jatropha husk sample in the presence of the zeolite.

Jourabchi et al. [29] also tested *Jatropha curcas* seed oil cake in fixed-bed pyrolysis. The biomass characterization showed that 70% of the total volatiles separation occurred at temperatures below 650 K, which is relatively low, reducing the energy consumption during the pyrolysis process. The amount of moisture content both from the thermogravimetric analysis (TGA) and from the oven drying method have matching results of below 4 wt.%, which is also slow. The authors pointed out that with moisture content below 10%, the drying process can be skipped completely before pyrolysis which is an advantage of this biomass source since energy is saved for the total bio-oil production process. According to their findings, below 573.15 K, no noticeable bio-oil product was observed because the heat was sufficient to crack the hemicellulose only and to produce mainly CO and CO_2 gases. Within 623.15 K to 773.15 K, the cellulose first breaks down, and then the lignin starts to crack down into char, water and heavy oil. Between 32-50% of bio-oil yield is achieved and 9-16 MJ/kg, both depending on the N_2 flow. The authors conducted another research to parametrically investigate and optimise bio-oil production from a fast pyrolysis process for comparison with conventional pyrolysis using a tubular furnace [35]. The authors pointed out that although rapid heating fast pyrolysis reduces the bio-oil yield, the gross calorific value and water content of bio-oil is improved. At optimum reaction temperature of 747.15 K and N_2 linear velocity of 0.0078 cm/s for fast pyrolysis, 40.93 wt.% of biomass was converted into bio-oil with a GCV of 16.92 MJ/kg, water content of 28.02 wt.% and pH of 7.01. They sentenced that according to the product characterization, the dehydrated bio-oil (FPDB), after reducing its sulphur contents, is suitable as burner fuel. It was also possible to emulsify it in 90% of diesel fuel.

Kongkasawan et al. studied the Jatropha seed oil cake as an alternative energy source via pressurized Pyrolysis. Concerning the physical and chemical characterization, the oil cake presented a HHV higher than other seed cakes such as Pongamia and Meem and higher of other biomass waste used for energy production such as rapeseed oil, corn stover, sugar cane bagasse, rice husk and cotton stalk [30]. According to their findings, the authors sentenced that the amount of biochar decreased with an increase of temperature. Pyrolysis gas production increased from 400-500ºC and then decreased from 500-600ºC, but the pyrolysis temperature did not affect the liquid product yield. Among all products at different operating temperatures, biochar yielded the highest amount at 37-44%, liquid product 24-27% and gas 13-21%. High carbon content present in the biochar showed a high potential application for activated carbon or fuel substitute. Bio-oil also contained high phenol and hydrocarbon compounds, which needed further upgrading process to make it acceptable to use as transportation fuel.

Vichaphund [17] investigated the effect of Jatropha waste: catalyst ratios, catalysts (CaO, Ni/CaO and Fe/CaO) were placed above the biomass layer at Jatropha waste: catalyst ratios of 1:1 or 1:5. The sample was pyrolyzed with the Pyroprobe set at 500ºC for 30 s. The pyrolysis vapors were identified by GC-MS. Without a catalyst, the fast pyrolysis of Jatropha residues led to the formation of diverse organic compounds that were classified into 10 groups. The major product was fatty acids 50.7%, mostly linoleic acid (C18:2). The level of nitrogen-containing compounds in the non-catalytic bio-oil derived from Jatropha residues was 20.3%. These included nitrile, amine, amide, piperidone, piperazine, pyrrole and indole derivatives resulting from the reaction between fatty acids and ammonia during biomass burning. Other oxygen-containing compounds were ketones (7.52%), phenols (5.09%), ethers (3.72%), alcohols (3%) and esters (1.99%). The formation of these volatile organic compounds resulted from three pyrolytic pathways (decomposition of lignin, depolymerization of cellulose and hemicellulose and pyrolytic ring scission of holocellulose). Ni/CaO showed the highest hydrocarbon selectivity (47.5%) at a 1:5 biomass:catalyst ratio.

Raja et al. [31] studied the flash pyrolysis of Jatropha oil cake in a fluidized bed reactor. Particularly, the influences of pyrolysis temperature, particle size range and nitrogen gas flow rate on the product yields. An electrically heated fluidized bed reactor was used. Nitrogen was used as the fluidizing gas. The fluidizing gas velocity was maintained greater than the minimum fluidization velocity. Sand of particle size 0.71 mm was used. The yield of oil increased from 42.15% to 64.25% when the pyrolysis temperature was increased from 350 to 500ºC. They reported that the concentration of fuel components in gas is increased as the particle size is increased from 0.6 to 1 mm. The maximum percentage of fraction was 0.7 and obtained at a particle size of 1 mm. The maximum oil yield of 64.25 wt.% was obtained at a pyrolysis temperature of 500ºC, particle size of 1 mm and nitrogen gas flow rate of 1.75 m^3/h. The calorific value of pyrolysis oil was found to be 19.66 MJ/kg.

Kim et al. [33]studied the pyrolysis of Jatropha seed cake and compared it with palm kernel shell and empty palm fruit bunches, as waste from the palm and Jatropha oil industries, in a fluidized bed (0.102 m id., 0.97 m high). The effects of bed temperature and gas flow rate on the product yields and properties of pyrolytic liquid were determined. The pyrolytic liquid product and fractionated oil yields of Jatropha cake were maximized at 48 wt.% and 32 wt.% with increase of bed temperature. The pyrolytic oils obtained from the wastes are characterized by more oxygen, lower HHVs, more nitrogen and less sulphur than petroleum fuel oils. The oils from Jatropha and palm contained more fatty acid and glycerides than other oils from lignocellulose biomass as they found comparing with other wastes and feedstocks. The finding indicates that they were similar to palm fatty acid distillate from palm oil and could be used as alternative feedstocks for biodiesel production using hydro-treating process, as the authors pointed out.

Imran et al. [34] studied the catalytic pyrolysis of Jatropha curcas seed cake and compared it with wood, using sodium based catalysts to produce a high quality bio-oil. The catalytic pyrolysis was carried out in two modes: in-situ catalytic pyrolysis and post treatment of the pyrolysis vapors. The in-situ catalytic pyrolysis was carried out in an entrained flow reactor system using a premixed feedstock of Na_2CO_3 and biomass and post treatment of biomass pyrolysis vapors was conducted in a downstream fixed bed reactor. They reported that both type of inorganic catalyzers can be used for the production of a high quality bio-oil from catalytic pyrolysis of oil-impregnated-wood and Jatropha cake. The catalytic bio-oil had very low oxygen content and a high calorific value up to 41.8 MJ/kg. The bio-oil consisted of high value chemical compounds mainly hydrocarbons and undesired compounds in the bio-oil. The post treatment of the pyrolysis vapors over a fixed bed of $Na_2CO_3/\gamma\text{-}Al_2O_3$ produced superior quality bio-oil compared to in-situ catalytic pyrolysis with

Na_2CO_3. As the authors concluded, the obtained high quality bio-oil may be used as a precursor in a fractionating process for the production of alternative fuels.

Naik [36] studied the product distribution pattern of the co-pyrolysis process involving lignocellulosic biomass and bituminous coal. The study was aimed at understanding the molecular level information about the pyrolysis oils obtained after co-pyrolysis. A 1:1 blend of Jatropha curcas seed cake and bituminous coal was selected as feedstock and was pyrolyzed under an inert environment in a fixed bed reactor. The resulted pyrolysis oil was separated into aqueous and organic phases and subjected to liquid-liquid extraction. The analysis revealed that organic and aqueous phases differed significantly owing to the presence of varied functional groups. The results were also compared with pyrolytic oils obtained from the feedstock separately. The organic phases revealed 25.1% hydrocarbons in Jatropha + coal derived pyrolysis. Phenolics were present in comparable amounts in organic phases. In contrast, the aqueous phases contained phenolics at 27.7% respectively. Aldehydes and ketones were prominently present in derived pyrolysis oil.

Other report was focused on [37] the catalytic upgrading of the pyrolytic vapours after fast pyrolysis of Jatropha cake. The GC/MS analyses for pyrolysis vapours show a range of aromatic hydrocarbons, hydrocarbon compounds, phenols, alcohols, aldehydes, ketones, acids and esters, furan and N-containing compounds. The result showed that high temperature had positive influence on the yields of pyrolytic products. Catalytic testing was performed by using Al_2O_3, ZrO_2 based catalysts and their modified ones with impregnation of Pd, Ru, and Ni, respectively. The Al2O3 and ZrO_2 were impregnated with CeO_2 to promote metal dispersion prior to deposition of Pd, Ru, or Ni. The hydrocarbon yields increased with increasing catalyst to Jatropha ratio in all catalysts. Even when some N-compounds formation suggested that further denitrogenation is required while pyrolysis with ZrO_2 had disadvantage on high yield of acid which could cause the corrosion problem, the authors concluded that overall performances of these two support catalysts are acceptable and can be considered as good candidates for bio-oil upgrading catalysts.

More recently, Piloto-Rodriguez et al. developed an integral study of the use of Jatropha curcas by-products as energy source in agroindustry [38]. Pfeil et al. [39, 40] published a full characterization of several biomasses included Jatropha and Moringa. On the other hand, Rodriguez et al. [41] assesses the environmental and economic issues related to the shell gasification of *Jatropha curcas*, and the simulation of the gasification of Jatropha shell was also conducted [42].

3. Conclusions

The use of the shell and husk by-products of the biodiesel production process from Jatropha curcas and Moringa oleifera is not well reported but there are enough reports demonstrating the feasibility of their use and excellent features as biomass feedstocks for thermochemical conversion. The economic feasibility of small/medium-scale gasification systems integrated to internal combustion engines using JC shell for producing electricity is reported. There is more studies respect the use of JC instead of Moringa. In any case, the implementation of these biomass will depend on disposal, therefore are only suitable in-situ in located specialized agro industrial facilities at local scale.

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Conflict of Interests

No potential competing interest is declared by the author.

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