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Production of Jet Biofuels from Catalytic Cracking of Vegetable Oils Using Acidic Catalysts

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AI and NAN designed the study, performed the statistical analysis, wrote the protocol. Authors SAM, MAY and MB managed the analyses of the study and wrote the first draft of the manuscript. Author MB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Two vegetable oils were used to obtain Jet biofuels by catalytic cracking using two acidic catalysts (alumina and clay). The reaction conditions were studied including: catalyst ratio (0.2-1%), reaction time and temperature. The obtained biojet fuels were specified and compared according to ASTM specifications. The results of the study showed that the produced biojets are comparable to the petroleum derivatives. Increasing the catalyst ratio, time and temperature of the process were increased the efficiency of the produced fuels and narrow the differences between their properties and the commercial fuel. The obtained fuels were blended by JET A-1 in different ratios and the results of the blends were studied according to ASTM specifications.

Keywords: Jatropha oil; castor oil; catalytic cracking; biofuel; JET A.

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1. INTRODUCTION

Petroleum is the main source of chemicals used in our life. Furthermore, petroleum is the key feedstock for fuel, lubricants and heat energy. It is known that petroleum as nonrenewable energy source will diminish within less than 50 years. So, it is a requirement to find another energy resources to compensate the expected energy shortage. In addition, petroleum fuels by their different types have several hazardous gaseous products including NO_x and SO_x. These gases have many disadvantageous and lethal effects on the environment including: soil, water and atmosphere. Biofuels were the suggested solutions for all of these problems. Biofuels are characterized by their renewable sources as vegetable oils and low toxicity for environment, in addition to the low emissions of acidic exhausts. Aviation fuel, a petroleum-based fuel used to power aircraft, has stricter quality requirements than fuels used in road transport. Jet fuel is a type of aviation fuel designed specifically to power gas-turbine engines. According to a report from the U.S. Energy Information Administration (EIA) [1], 4 gallons out of every 42-gallon barrel of crude oil are used to produce jet fuel. The worldwide aviation industry consumes approximately 1.5–1.7 billion barrels of conventional jet fuel per year [2-3]. Fuel is the largest operating cost in the aviation industry, and the unstable prices of crude oil hamper long-term planning and expense budgeting. Renewable feedstock-derived jet fuels can reduce the dependency of the aviation industry on one single energy source, avoiding the volatility of petroleum prices, and potentially reducing greenhouse gas (GHG) emissions [3]. A diversified, homegrown, and renewable feedstock-based fuel system is crucial in the policy to realize energy safety and to increase environmental stewardship. Numerous researches were addressed a range of jet fuel as well as the mixing relation of biofuels with petroleum jet fuels. Investigation recommends that a practical market of biofuels can be preserved as 1% of world jet fuel source is replaced by a biofuel [3], with aggregation of higher blending ratio for future years, such as 25% by 2020, 30% by 2030, and 50% by 2040 [4-5]. Biofuel is produced by cracking of various vegetable oils such as Alcea pallid oil [6], wood [7], soybean [8], palm [9], cotton seeds [10], Jatropha [11] and waste cooking oils [12]. Cracking processes are achieved by thermal, catalytic reactions [13]. Transesterification reactions can be performed by alkali catalysts [14], metal oxides [15] and modified zeolites [16,17,18]. Castor oil is planted in Upper Egypt and is widely spread in the south and western regions in 2,000,000 ha, and the yearly production is above 250,700 tons [19]. The yield of the Castor oil seed is about 40-60 %. In addition, the Castor trees are gaining importance due to its low maintenance and fewer crop husbandry management practices required [19]. In addition, Jatropha oil is promising because it is non-edible with no opposition by nutrition harvests. This paper aimed to prepare and evaluate the biofuels that is produced from the catalytic cracking of castor and jatropha oils, and compare their fuel properties with JET A-1 fuel using ASTM and IP Standards.

2. MATERIALS AND METHODS

2.1 Materials

Jatropha and Castor oils were obtained from jatropha and castor seeds via hydraulic pressing; acidic catalysts (Alumina and Montmorillonite-HCl) were purchased from (Sigma-Aldrich, Germany).

2.2 Methods

2.2.1 Extraction of jatropha and castor oils

Dry seeds of Jatropha and Castor trees (1000 g) were hydraulically crushed and pressed to obtain their oils, then centrifuged for removing of solids, contaminations and water.

2.2.2 Catalytic cracking of jatropha and castor oils into biofuels

The cracking techniques were achieved as follows: 150 mL of oils were charged in 500 mL flask and the tested catalysts were added at amounts of 0.2-1% per weight of oil. The reaction was stirred and permitted to heat for 5 h at 260^{o}C. The products were claimed using a condenser and the volume of each product was monitored. The attained biofuels were established in a separating funnel to separate water followed by centrifugation to replace contaminated water. At the end of the reaction: biofuel, water, solids were in the following amounts (75%, 15%, 3%) and some vapors. Finally, the obtained biofuels were distilled until 250^{o}C and the products were separated. At this point, the obtained biofuels were ready to be used as jet biofuels.

2.2.3 Oil characterization

The fatty acid profile of the oils was determined using Chromatographic analysis in the following setup: GC-7890A instrument equipped with DB-23 column, 60 mm x 0.25 mm, i.d. of 0.25 µm. The properties of different oils were determined as stated by ASTM specifications including: iodine value, acid value, kinematic viscosity at 40ºC, density, cloud point, pour point, oxidation stability, and sulphur content.

2.2.4 Biofuel specification

The characteristic specifications of the different biofuels including: density, flash point, pour point, cloud point, kinematic viscosity at 40ºC, water content, total sulfur, copper corrosion strip, carbon residue and ash content were also determined according to (ASTM) specifications [20-29].

The suitable blends between the obtained biofuels and JET A-1 fuel were defined. The standard properties of the different biofuel mixes were comparable to fuel properties of JET A-1 fuel according to (ASTM) and (IP) specifications.

3. RESULTS AND DISCUSSION

3.1 The Characteristic Properties of Vegetable Oils

Table 1 represents the fatty acid profiles and the properties of the used oils.

3.2 Properties of the Obtained Biofuels

There are several parameters, which affect the conversion reaction of Jatropha and Castor oils into biofuels including catalyst type, catalyst ratio (%), conversion time and temperature. These parameters were studied to attain the optimized conversion reaction conditions. The characteristic specifications of the obtained biojets were determined according to (ASTM) specifications. The measured characteristics such as: density, flash point, pour point, cloud point, kinematic viscosity at 40ºC, water content, total sulphur, copper corrosion strip, carbon residue and ash content were listed in Table 2.

3.3 The suitable Blend Between the Obtained Biofuel and Gas Oil Fuel

In this study, many blends were made between the prepared biofuels and JET A-1. The most appropriate mix of the petroleum Jet (JET A-1) and the obtained biofuels was 5% biofuel + 95% JET A-1. The results of these jet biofuel blends were in adequate variety related to JET A-1 rendering the ASTM and IP specifications Tables 3-6. The “Existent Gum” of the prepared jet biofuels increases than ASTM specifications (more than 7 mg/100 ml), when the mixing proportion of the biofuels to JET A-1 fuel increases than 5%.

3.3.1 Density

The density of the biofuel is representing the ratio between the weight of the biofuel in gram and its volume. The density is an important property in the fuel processing and ignition. That is due to high-density fuel has an extra weight loaded on the engines. That consumes extra amount of fuel during the ignition. In case of JET A-1 fuel, the density value was (0.8025 g/cm^3) referred to ASTM D-4052 [27]. The densities of the obtained bio-jet fuel mixes are located within the limits of ASTM specifications (0.8037 to 0.8039 g/cm^3).

3.3.2 Flash Point

Flashpoint is defined as the temperature where the fuel-air mixture can ignite by a flame spark [30]. For JET A-1 fuel, the flashpoint should be (min. 38^{o}C) according to IP 170 [31]. The obtained flash point values of the prepared jet biofuel blends were within the range of IP (44ºC – 46ºC).

3.3.3 Freezing point

The freezing point of the fuel is defined as the temperature at which hydrocarbon crystals, formed on cooling, disappear when the temperature of the fuel is allowed to rise under specified conditions. For JET A-1 fuel, the freezing point should be (max. -47ºC) according to ASTM D-7153 [32]. The obtained freezing point values of the prepared jet biofuel blends were within the range of ASTM (-53ºC to -54ºC).

3.3.4 Distillation

This test method covers the atmospheric distillation of petroleum products using a laboratory batch distillation unit to determine quantitatively the boiling range characteristics of such products as light and middle distillates. The obtained distillate values of the prepared jet biofuel blends were within the range of ASTM D-86 [33].

Table 1. The fatty acid profiles and properties of jatropha and castor oils

Property	Castor oil	Jatropha oil
Fatty acid composition (wt %):		
Palmitic acid (C16:0)	1.00	15.20
Palmitoleic acid (C16:1)	-----	0.70
Stearic acid (C18:0)	-----	6.80
Oleic acid (C18:1)	3.00	44.60
Linoleic acid (C18:2)	5.00	32.20
Linolenic acid (C18:3)	1.00	-----
Arachidic acid (C20:0)	-----	0.20
Ricinoleic acid (C18:1, OH)	89.00	-----
Acid value, (mg KOH/g)	3.0	3.80
Kinematic Viscosity @ 40ºC, (mm^2/s)	43.0	37.0
Density, (g/cm^3) at 15ºC	0.959	0.910
Cloud point, (ºC)	8	8
Pour point, (ºC)	3	3
Oxidation stability, (h)	5.5	2.56
Iodine value, gI_2/100 g oil	80.5	104.46
Sulphur content %	0	0

Table 2. Physical and chemical properties of biofuels results from catalytic cracking of jatropha oil with alumina catalyst at different concentrations

Properties		Catalyst ratio				
		0.2%	0.4%	0.6%	0.8%	1%
Density @ 15ºC	(gm/cm^3)	0.8989	0.8991	0.8991	0.8992	0.8992
Flash Point (P.M.C.C)	(ºC)	45	44	45	45	44
Pour Point	(ºC)	-3	-6	-3	-6	-3
Cloud Point	(ºC)	3	6	3	3	6
Kinematic Viscosity at 40ºC	(CSt)	6.04	6.07	6.1	6.11	6.11
Water Content	(% vol)	15	14	17	15	16
Total Sulphur	(% wt)	0.01	0.01	0.02	0.02	0.02
Copper Corrosion Strip at 50ºC/3h		1A	1A	1A	1A	1A
Carbon Residue	(%wt)	0.05	0.06	0.06	0.06	0.07
Ash Content	(% wt)	Nil	Nil	Nil	Nil	Nil

Table 3. Physical and chemical properties of jet biofuels "B5" (5% Biofuel* + 95% Jet) *Biofuel: Jatropha Oil with Alumina Catalyst (0.2, 0.4, 0.6, 0.8, 1 % conc.)

Properties	Jet Biofuels "B5" (5% Biofuel* + 95% Jet)					JET A-1 fuel	Specification limits
	0.2%	0.4%	0.6%	0.8%	1%		
Colour Saybolt	15	15	15	15	15	17	Reported
Density @ 15ºC (gm/cm^3)	0.8037	0.8037	0.8038	0.8038	0.8039	0.8025	0.775 (min.) to 0.840 (max.)
Flash Point (Abel Closed Cup) (ºC)	46	44	45	45	45	42	38 (min.)
Freezing Point (ºC)	-54	-53	-54	-54	-53	-52	-47 (max.)
Distillation:							
Initial Boiling Point (ºC)	152	152	153	152	153	152	Reported
Fuel Recovered :	160	159	161	160	161	166	205 (max.)
10% vol @, (ºC)	182	180	182	181	182	186	Reported
50% vol @, (ºC)	222	221	221	222	222	226	Reported
90% vol @, (ºC)	244	243	244	244	244	251	300 (max.)

Properties	Jet Biofuels "B5" (5% Biofuel* + 95% Jet)					JET A-1 fuel	Specification limits
	0.2%	0.4%	0.6%	0.8%	1%		
End Point (ºC)	0.5	0.5	0.5	0.5	0.5	0.5	1.5 (max.)
Residue (% vol)	--	--	--	--	--	--	1.5 (max.)
Loss (% vol)							
Copper Corrosion Strip@100ºC/2 h	1	1	1	1	1	1	1 (max.)
Existent Gum (mg/100 ml)	1.6	1.7	1.8	1.7	1.8	1.2	7 (max.)
Electrical Conductivity (pS/m @ºC)	320 @25ºC	316 @25ºC	322 @25ºC	325 @25ºC	320 @25ºC	326 @25ºC	50(min.) to 600 (max.)

Table 4. Physical and chemical properties of jet biofuels "B5" (5% Biofuel* + 95% Jet) *Biofuel: castor oil with alumina catalyst (0.2, 0.4, 0.6, 0.8, 1 % conc.)

Properties	Jet Biofuels "B5" (5% Biofuel* + 95% Jet)					JET A-1 fuel	Specification limits
	0.2%	0.4%	0.6%	0.8%	1%		
Colour Saybolt	15	15	15	15	15	17	Reported
Density @ 15ºC (gm/cm^3)	0.8038	0.8038	0.8039	0.8039	0.8039	0.8025	0.775 (min.) to 0.840 (max.)
Flash Point (Abel Closed Cup) (ºC)	45	45	46	44	45	42	38 (min.)
Freezing Point (ºC)	-53	-54	-54	-54	-54	-52	-47 (max.)
Distillation:							
Initial Boiling Point (ºC)	153	153	153	153	153	152	Reported
Fuel Recovered :	162	161	162	162	162	166	205 (max.)
10% vol @, (ºC)	182	181	183	182	182	186	Reported
50% vol @, (ºC)	223	223	224	222	221	226	Reported
90% vol @, (ºC)	245	245	244	245	244	251	300 (max.)
End Point (ºC)	0.5	0.5	0.5	0.5	0.5	0.5	1.5 (max.)
Residue (% vol)	--	--	--	--	--	--	1.5 (max.)
Loss (% vol)							
Copper Corrosion Strip@100ºC/2h	1	1	1	1	1	1	1 (max.)
Existent Gum (mg/100ml)	1.7	1.7	1.8	1.8	1.8	1.2	7 (max.)
Electrical Conductivity (pS/m @ºC)	325 @25ºC	318 @25ºC	315 @25ºC	320 @25ºC	324 @25ºC	326 @25ºC	50(min.) to 600 (max.)

3.3.5 Existent gum

The existent gum represents the evaporation residue of aviation fuels, without any further treatment. For JET A-1 fuel, the existent gum should be (max. 7 mg/100 ml) according to ASTM D-381 [34]. The obtained existent gum values of the prepared jet biofuel blends were within the range of ASTM (1.6 to 1.8 mg/100 ml).

3.3.6 Electrical conductivity

This test method covers the determination of the electrical conductivity of aviation and distillate fuels with and without a static dissipator additive. For JET A-1 fuel, the electrical conductivity was (326 pS/m at 25ºC) according to ASTM D-2624 [35]. The obtained electrical conductivity values of the prepared jet biofuel blends were within the range of ASTM (315 to 328 pS/m at 25ºC) [36].

Table 5. Physical and chemical properties of jet biofuels "B5" (5% Biofuel* + 95% Jet) *Biofuel: jatropha oil with montmorillonite-hcl catalyst (0.2, 0.4, 0.6, 0.8, 1 % conc.)

Properties	Jet Biofuels "B5" (5% Biofuel* + 95% Jet)					JET A-1 fuel	Specification limits
	0.2%	0.4%	0.6%	0.8%	1%		
Colour Saybolt	15	15	15	15	15	17	Reported
Density @ 15ºC (gm/cm^3)	0.8037	0.8038	0.8038	0.8038	0.8039	0.8025	0.775 (min.) to 0.840 (max.)
Flash Point (Abel Closed Cup) (ºC)	44	45	45	45	45	42	38 (min.)
Freezing Point (ºC)	-54	-54	-54	-54	-54	-52	-47 (max.)
Distillation:							
Initial Boiling Point (ºC)	152	153	153	153	153	152	Reported
Fuel Recovered :	161	163	163	159	162	166	205 (max.)
10% vol @, (ºC)	182	183	184	181	182	186	Reported
50% vol @, (ºC)	224	224	224	221	224	226	Reported
90% vol @, (ºC)	244	245	246	243	244	251	300 (max.)
End Point	0.5	0.5	0.5	0.5	0.5	0.5	1.5 (max.)
(ºC)	--	--	--	--	--	--	1.5 (max.)
Residue (% vol)							
Loss (% vol)							
Copper Corrosion Strip@100ºC/2h	1	1	1	1	1	1	1 (max.)
Existent Gum (mg/100ml)	1.6	1.7	1.7	1.7	1.8	1.2	7 (max.)
Electrical Conductivity (pS/m @ºC)	321 @25ºC	325 @25ºC	320 @25ºC	322 @25ºC	325 @25ºC	326 @25ºC	50(min.) to 600 (max.)

Table 6. Physical and chemical properties of jet biofuels "B5" (5% Biofuel* + 95% Jet) *Biofuel: castor oil with montmorillonite-HCL catalyst (0.2, 0.4, 0.6, 0.8, 1 % conc.)

Properties	Jet Biofuels "B5" (5% Biofuel* + 95% Jet)					JET A-1 fuel	Specification limits
	0.2%	0.4%	0.6%	0.8%	1%		
Colour Saybolt	15	15	15	15	15	17	Reported
Density @ 15ºC (gm/cm^3)	0.8037	0.8037	0.8038	0.8039	0.8039	0.8025	0.775 (min.) to 0.840 (max.)
Flash Point (Abel Closed Cup) (ºC)	45	44	44	45	46	42	38 (min.)
Freezing Point (ºC)	-54	-53	-53	-54	-54	-52	-47 (max.)
Distillation:							
Initial Boiling Point (°C)	153	153	152	153	153	152	Reported
Fuel Recovered :	163	162	162	161	161	166	205 (max.)
10% vol @, (ºC)	184	183	184	181	182	186	Reported
50% vol @, (ºC)	224	223	224	222	222	226	Reported
90% vol @, (ºC)	246	244	245	245	244	251	300 (max.)
End Point	0.5	0.5	0.5	0.5	0.5	0.5	1.5 (max.)

Properties	Jet Biofuels "B5" (5% Biofuel* + 95% Jet)					JET A-1 fuel	Specification limits
	0.2%	0.4%	0.6%	0.8%	1%		
(ºC)	--	--	--	--	--	--	1.5 (max.)
Residue (% vol)							
Loss (% vol)							
Copper Corrosion Strip@100ºC/2h	1	1	1	1	1	1	1 (max.)
Existent Gum (mg/100ml)	1.7	1.7	1.8	1.7	1.7	1.2	7 (max.)
Electrical Conductivity (pS/m @ºC)	318 @25ºC	328 @25ºC	325 @25ºC	320 @25ºC	328 @25ºC	326 @25ºC	50(min.) to 600 (max.)

4. CONCLUSIONS

From the results obtained in this study, the following conclusions can be recorded:

1. Castor and jatropha oils were improved as biofuels using acidic heterogeneous catalysts at various ratios (0.2-1%).
2. The specifications of the obtained biofuels were comparable to ASTM specifications.
3. The suitable blend between the obtained biofuels and JET A-1 was (5% Biofuel + 95% JET A-1 fuel).
4. The results of these jet biofuel blends were in acceptable range compared to JET A-1 fuel according to the standard values of (ASTM) and (IP) specifications.
5. When the blending ratio of the prepared biofuels to JET A-1 fuel increases than 5%, the "Existent Gum" of the prepared jet biofuels increases than ASTM specifications (more than 7 mg/100 ml).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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