

Hydrocracking of Jojoba Oil for Green Fuel Production

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ABSTRACT

The fast depletion of petroleum crude oil reserves and the serious consideration of environmental issues make the implementation of sustainable energy sources a crucial issue worldwide. Biofuel derived from vegetable oils is receiving a great attention as one of the most suitable and logical alternatives of fossil fuels. Therefore, the production of petroleum-like fractions from nonedible oil extracted from jojoba seeds is the main objective of this study.

Hydrocracking technique has been applied here, using a fixed bed high pressure flow reactor system and using zeolite as a catalyst. A series of experiments were carried out in the temperature ranges from 350-425°C at the pressure of 1.0-5.0 MPa, liquid hour space velocity (LHSV) of 1-5 hr⁻¹, and H₂ to oil feed ratio of 1600 l/l in order to elucidate the influence of operating conditions on the quantity and quality of the biofuel attained.

The major products obtained from hydrocracking of jojoba oil feedstock were organic liquid products contaminated with some water and gases. The yield and conversion were estimated. The cracked products were analyzed and compared with that of the feed via FTIR, GC, ASTM distillation, and some routine testes. The organic liquid layers were fractionated to gasoline, kerosene, and gas oil. The results reveal that the main constituent lies in the gasoline range, which was favored at high temperature and pressure and low LHSV.

Keywords: Biofuel, Hydrocracking, Jojoba Oil, Zeolite, Nonedible Oil

INTRODUCTION

Due to the diminishing petroleum reserve, a worldwide trend is concentrated on searching for alternative and renewable energy sources [1-3]. The biofuels derived from vegetable oils are attracting increased interest in this respect [4,5]. They are nontoxic, biodegradable, and environmentally friendly, since they show great reduction in the emission of harmful matters such as carbon monoxide, sulfur compound,

polyaromatics, smoke, etc. [6,7].

Biodiesel production from the transesterification of vegetable oils is currently the primary route for the production of biofuels from plant oils [8]. The transesterification process is the reaction of a lipid with a short chain alcohol, mainly methanol, to form fatty acid methyl ester (biodiesel) and byproducts [9-11]. Although this process has many benefits, the usage of FAME is connected with numerous problems as compared to the use

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of petroleum-based fuel. Some of the disadvantages ensuing employing FAME are deposit formation in the fuel system and combustion chamber, poor storage (low oxidation and heat stability) due to the double bond in the molecules, water adsorption and shortened lifetime of the engine oils, cost, high pour point versus petrodiesel, etc.

It is possible to eliminate or even to minimize the majority of these drawbacks, if vegetable oils are converted to a paraffin-rich mixture of hydrocarbons, which then makes it appropriate to be used in vehicles engines. Some modern technologies such as thermo-catalytic processing of vegetable oils appeared for producing alternative motor fuels, namely gasoline and diesel [12-14]. Three main concepts are described in literature, namely hydroprocessing, thermal, and catalytic cracking [15-17]. These technologies have significant potential as the produced oils have better fuel properties than that obtained via transesterification; in addition, they employ the existing infrastructure of petroleum refineries.

Considerable efforts have been devoted to the promotion of cracking techniques for the production of pet-like fractions from vegetable oils, which is regarded as one of the most reasonable and promising technologies for high yield of liquid products [17-19]. Since the introduction of catalytic cracking, the initial catalysts were clays and amorphous Si-Al and evolved with time to zeolites, particularly the use of rare earth- γ (REY), and finally to the ultra stable- γ (USY, REUSY). Zeolites have shown excellent performance as solid acid cracking catalysts due to their higher selectivity [14,19].

Hydrotreating and hydrocracking of vegetable oils such as soybean sunflower and rapeseed has been reported [20-22]. Considering the problem of biofuels competing with food sources, nonedible plant oil was used as a feedstock to produce green transportation fuel. The aim of this study is to investigate the

feasibility of producing high quality petroleum-like fraction by hydrocracking the nonedible jojoba oil and to elucidate the optimum operating conditions for the attainment of the maximum yield of the desired components.

EXPERIMENTAL PROCEDURES

In this study, hydrocracking of jojoba oil purchased from Egyptian Company for Natural Oils has been employed as a feedstock. HYDEX-L, a novel zeolite-based catalyst was developed by the Sud-Chemie Group for dewaxing the lube oil. It selectively hydrocracks waxy molecules to short chain products. HYDEX-L is extruded square in shape with a size of 1.5×2.5 mm, a surface area of 289.75 m²/gm, a total pore volume of 0.3331 cc/gm, and an average pore radius of 22.99 Å. It was used here to catalyze the hydrocracking reaction. The catalyst was dried at 120 °C for 3 hrs, then calcined at 450 °C for 6 hrs in air, and reduced at 450 °C under 1 MPa hydrogen pressure for 2 hrs.

A series of experiments were conducted to explore the influence of the operating conditions on the quantities and qualities of the obtained products. The reaction has been performed using a continuous high pressure microreactor (cata-test unit) Figure 1.

The apparatus consists mainly of 50 cm length stainless steel reactor, with an internal and external diameter of 19 and 27 mm respectively. It is divided into three zones, each of which has its individual heating element and temperature controller. 30 gm (equivalent to 46 ml) of the catalyst mixed with the same volume of ceramic was charged into the middle zone of the reactor. Hydrogen gas was supplied to the unit from an H₂ cylinder, while the liquid feed was pumped to the top of the reactor by means of a piston pump having an adjusting knob.

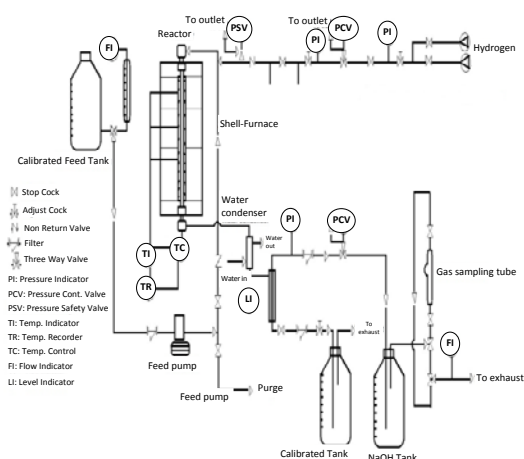


Figure 1: High pressure catalyst activity testing unit

The hydroconversion reaction of jojoba was carried out in various operating conditions. Firstly, the unit was flushed with hydrogen gas before the feedstock oil was fed by the pump; then it was kept under hydrogen gas pressure to check any leakage. Thereafter, the operating conditions in the hydroconversion runs were adjusted as required. Once a steady state had reached, the feed was pumped and the reactor effluent was cooled in a water condenser before separating its liquid and gas phases. The liquid product (organic and aqueous fractions) was collected in a receiver, while the gases were passed through a gas meter to the outlet. The contaminated water involved in the liquid yield was removed after settling in a separating funnel for 24 hrs. Anhydrous sodium sulphate was then added to the organic product to eliminate any traces of water still existed. The effluent gases and liquid yields were estimated.

Weight of gases (gr) = Weight of jojoba oil feed (gr) - Weight of total liquid product (gr).

$$\text{Total conversion (wt.\%)} = \frac{\text{gases (gr)} + \text{water (gr)} + \text{biofuel yield (gr)}}{\text{Feed (gr)}} \times 100 \quad (1)$$

The weight of biofuel yield, separated from the organic liquid product, was taken as the weight of fraction distilled below the boiling point of

jojoba oil (< 323 °C).

$$\text{Biofuel selectivity (\%)} = \frac{\text{Biofuel yield (gr)}}{\text{Converted feed}} \times 100 \quad (2)$$

The organic fraction was analyzed and evaluated according to the different standard ASTM methods, including density (D-287), kinematic viscosity (D-455), sulfur content (D-4294) using x-ray fluorescence sulfur meter, and distillation (D-86). In addition, the virgin oil and the degraded organic product obtained at 425 °C were analyzed via GC and FTIR techniques. The gas chromatographic apparatus, Agilent 6890, equipped with flame ionization detector (FID) was employed. Separation was performed on HP-1 column with a length of 30 meter and an ID of 0.25 mm. The temperature of injector and detector was set at 300 °C. The FTIR spectroscopy was determined using Nicolet-LOFT-IR, Nicolet IS-10.

RESULTS AND DISCUSSION

The optimization of the operating conditions to assess the highest yield of the desired product will be beneficial. Therefore, a series of experiments were conducted to explore the influence of each operating factor on the product distribution of the hydrocracked jojoba oil and to determine the best conditions for the attainment of the maximum yield of biofuel fraction.

Effect of Liquid Hour Space Velocity (LHSV)

The liquid hourly space velocity (LHSV) is an important operating parameter for regulating catalyst performance. The efficiency of this factor on hydrocracking reaction is one of the main premises of the present investigation. In this respect, hydrocracking of jojoba oil was

carried out at three various LHSV's of 1, 2.5, and 5 hr⁻¹ in the same experimental conditions, i.e. temperature of 400 °C, pressure of 2.5 MPa,

and H₂/oil ratio of 1600 l/l, and using a zeolite catalyst. The quality and yields of the obtained products were evaluated, and the results are summarized in Table 1.

Table 1: Distribution of the hydrocracked products obtained at various LHSV's; temperature: 400 °C, pressure: 2.5 MPa, and H₂/feed: 1600 l/l

| Hydrocracked Products | 1 hr ⁻¹ | 2.5 hr ⁻¹ | 5 hr ⁻¹ |
|--|--------------------|----------------------|--------------------|
| Total conversion (wt.%) | 99.44 | 99.17 | 99 |
| Hydrocracked products (wt.%) | | | |
| Gases | 18.04 | 17.84 | 2.34 |
| Liquid | 81.96 | 82.16 | 97.66 |
| Water content | 6.74 | 4.49 | 3.30 |
| Oil content | 75.22 | 77.67 | 94.36 |
| Density at 20 °C | 0.8110 | 0.8120 | 0.8215 |
| Kinematic viscosity at 40°C | 1.0714 | 1.1588 | 2.5250 |
| Sulfur content (ppm) | 0.029 | 0.011 | 0.016 |
| ASTM distillation, (vol. %) | | | |
| IBP (°C) | 50 | 50 | 50 |
| 10 | 70 | 70 | 70 |
| 20 | 80 | 80 | 110 |
| 30 | 100 | 100 | 140 |
| 40 | 110 | 120 | 150 |
| 50 | 120 | 130 | 180 |
| 60 | 150 | 140 | 273.2 |
| 70 | 150 | 154.9 | 294.5 |
| 80 | 237.7 | 219.7 | 305.2 |
| 90 | 250 | 250 | 305.2 |
| FBP | 250 | 250 | 305.2 |
| Recovered (vol.%) | 90 | 91 | 97 |
| Unconverted and residue (vol.%) | 1 | 1 | 1 |
| Loss (vol.%) | 9 | 8 | 2 |
| Biofuel yield (wt %) | 74.62 | 76.84 | 93.36 |
| Biofuel selectivity (%) | 75.04 | 77.48 | 94.3 |

The data demonstrate that approximately the whole feedstock was entirely converted to hydrocracked products, at all the LHSV applied. Although the conversion is a key assessment of catalyst activity, higher conversion may not result in a higher yield of the desired components. Beside gases, the effluent liquid products contain organic and aqueous fractions, some residue, and

unconverted oil. Among these, the most demandable component is the hydrocracked liquid organic fraction which is mainly composed of alkanes (biofuel).

The depicted results reflected the distinct diminution of the attainable liquid yield and oil content by reducing LHSV from 5 down to 1 hr⁻¹. The overall decreasing trend that observed upon lessening the LHSV is accompanied by the augmentation of gas formation from 2.34 to 18.04 wt.%. This is anticipated since diminishing LHSV implies a longer residence time of the feed in the catalyst section in the reactor, which gives more opportunities for the intensive cracking to proceed, leading to the predomination of gases on the account of the liquid yield.

On the other hand, the concentration of the aqueous layer in the cracked products is also enhanced with minimizing LHSV, since 3.3 wt.% of water was achieved at an LHSV of 5 hr⁻¹ and increased to be 6.74 wt.% at an LHSV of 1 hr⁻¹. This may be ascribed to the predomination of hydrodeoxygenation reaction which was favored at longer contact times.

In this study, ASTM distillation was implemented to determine the boiling range distribution of the organic liquid products obtained under the various conditions applied. In addition, the boiling point of crude joboba oil was determined and found to be, mainly, above 323 °C. Heavy molecules, with boiling points higher than 323 °C, were considered to be the unconverted part of the feed and residue which cannot be utilized as biofuels. It is evident from the accessible data declared in Table 1 that a good yield of petroleum-like fraction, which is the most significant constituent in request, can be obtained at an LHSV of 5 hr⁻¹, at which the highest yield and selectivity of 93.36 wt.% and 94.3% respectively were accomplished. Decreasing the LHSV to 2.5 and 1 hr⁻¹ leads to an enhancement of the undesirable components such as water and gasses at the expense of the biofuel attained.

Moreover, the produced biofuels were fractionated and separated into three portions, according to their boiling ranges, i.e. (50-150°C), (150-250°C), and (250-323°C), for gasoline, kerosene, and gas oil respectively. The influence of LHSV on the amount of each of the previously mentioned fractions in the produced biofuel can be deduced from Figure 2. It could be noticed that the substantial conversion to biofuel, frequently composed of gas oil and considerable amount of gasoline distillates, is accomplished at an LHSV of 5 hr⁻¹. Upon reducing the LHSV to 2.5 hr⁻¹ or less, the augmentation of gasoline fraction was occurred owing to the degradation of the heavier fractions, which transform to gasoline at such a high residence time. The most suitable LHSV value in getting a good yield of biofuel distillates involving the best concentration of gas oil is 5 hr⁻¹.

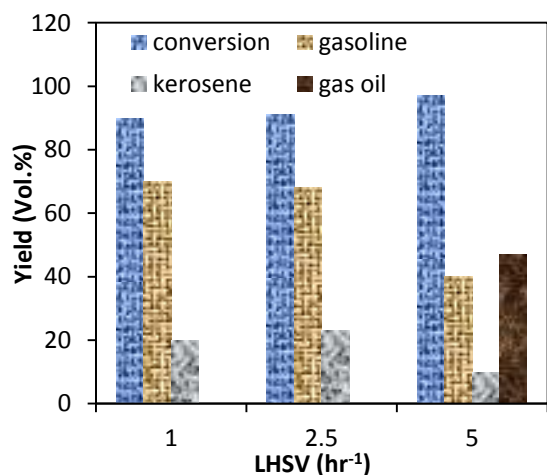


Figure 2: Distribution of the individual fractions of the biofuel obtained as a function of LHSV

Effect of Hydrogen Pressure

The influence of hydrogen pressure, under constant experimental conditions, can be deduced from the results listed in Table 2. These data reveal a significant enhancement of the converted yield from 66.26 to about 99 wt.%, accompanied by a pronounced exhibition in the quantities of the produced biofuel fraction as the applied H₂ pressure in the reactor increased beyond 1 MPa.

Simultaneously, both density and kinematic viscosity of the obtained oil are also reduced. This situation is expected since hydrocracking reaction can be promoted at sufficiently high pressures, which leads to the predomination of lighter components in the obtained products.

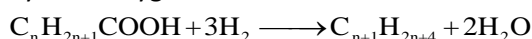
Table 2: Distribution of the hydrocracked products obtained at various H₂ pressures; temperature: 400°C, LHSV: 5 hr⁻¹, and H₂/feed: 1600 l/l

| Hydrocracked Products | 1.0 MPa | 2.5 MPa | 5.0 MPa |
|--|--------------|--------------|---------------|
| Total conversion (wt.%) | 66.26 | 99 | 99.065 |
| Hydrocracked product (wt.%) | | | |
| Gases | 0.70 | 2.34 | 4.64 |
| Liquid | 99.30 | 97.66 | 95.36 |
| Water content | 3.11 | 3.30 | 7.45 |
| Oil content | 96.19 | 94.36 | 87.90 |
| Density at 20 °C (gr/m ³) | 0.8295 | 0.8215 | 0.8131 |
| Kinematic viscosity at 40 °C | 3.9577 | 2.5250 | 1.0495 |
| Sulfur content (ppm) | 0.012 | 0.016 | 0.02 |
| ASTM distillation (vol. %) | | | |
| IBP | 60 | 50 | 40 |
| 10 | 80 | 70 | 60 |
| 20 | 120 | 110 | 90 |
| 30 | 160 | 140 | 110 |
| 40 | 280.3 | 150 | 120 |
| 50 | 301.5 | 180 | 130 |
| 60 | 301.5 | 273.2 | 150 |
| 70 | - | 294.5 | 170 |
| 80 | - | 305.2 | 273.2 |
| 90 | - | 305.2 | 273.2 |
| FBP | 301.5 | 305.2 | 273.2 |
| Recovered (vol.%) | 65 | 97 | 92 |
| Unconverted and residue (vol.%) | 34 | 1 | 1 |
| Loss (vol.%) | 1 | 2 | 7 |
| Biofuel yield (wt.%) | 62.45 | 93.36 | 86.965 |
| Biofuel selectivity (%) | 94.25 | 94.3 | 87.79 |

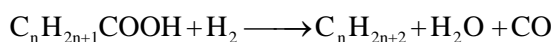
At the same time, increases in the amount of H₂O content in the liquid yield are observed too. This may be attributed to the elimination of O₂ from jojoba molecules as water, which is favored at higher H₂ concentration through the hydrodeoxygenation reaction, since decarbonylation and decarboxylation reactions are more favored at

lower H₂ pressure according to the following equations [23].

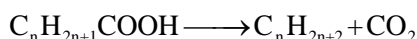
Hydrodeoxygenation reaction:



Hydrogenation:



Decarboxylation:



At an H₂ pressure of 1.0 MPa, only 62.45 wt.% from the virgin oil was transformed to biofuel. Upon increasing the pressure to 2.5 MPa, the recovered petroleum-like fractions increased to be 93.36 wt.%. Beyond which, i.e. at an H₂ pressure of 5.0 MPa, the conversion to biofuel was reduced to 86.97 wt.% due to the losses resulted from the relative abundance of the liberated gases owing to the enhancement of cracking reaction at such a high pressure.

As it is evident from Figure 3, the light fractions are more predominant at an H₂ pressure of 5.0 MPa, indicating that this technology is more suitable for gasoline production at relatively higher pressures rather than gas oil production and vice versa. The best yield of the desired liquid product can be achieved at a hydrogen pressure of 2.5 MPa. On the other hand, the data confirm the unsatisfactory results obtained for hydrocracking and biofuel yield in case of minimizing the reaction pressure to 1 MPa.

Effect of Reaction Temperature

Reaction temperature has been identified as the most crucial parameter for catalyst effectiveness. The influence of this factor on the yield and quality of the hydrocracked products of jojoba oil, using zeolite catalyst, was evaluated at three different reaction temperatures, i.e. 350, 400, and 425 °C. The remaining operating conditions were kept constant (pressure: 2.5 MPa, LHSV: 5 hr⁻¹, and H₂/oil ratio: 1600 l/l). The physicochemical characteristics and distribution of the main

products are represented in Table 3.

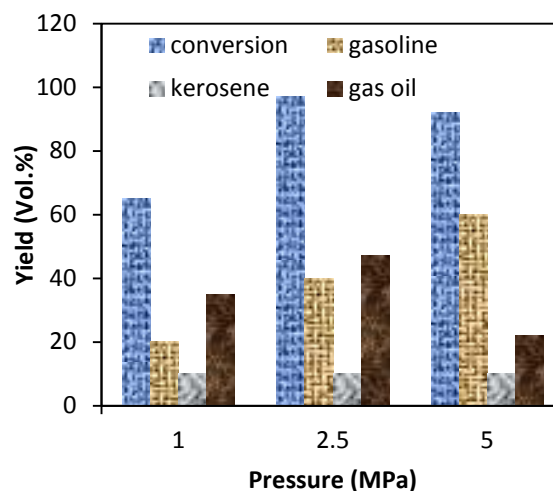


Figure 3: Distribution of the individual fractions of the biofuel obtained as a function of pressure

As can be observed from the depicted data, the amount of the converted crude jojoba is 61.36 wt.%, based on feed at 350°C. Beyond this temperature, i.e. at 400 and 425°C, almost a complete conversion of the feed to hydrocracked constituents was occurred. Nevertheless, at 425°C, the obtained liquid included somewhat lesser content of oil, amounting to 90.6 wt.%, compared to 94.36 wt.% achieved at 400°C. This can be ascribed principally to the contamination of the produced liquid with more water at the expense of the oil concentration. This water has been resulted through the hydroconversion of some of jojoba oil to alkanes via decarbonylation and/or hydrodeoxygenation of COOH group involved in the structure of jojoba molecule. The formation of water is more favored at elevated temperatures owing to the acceleration of the rate of such reactions at high temperatures.

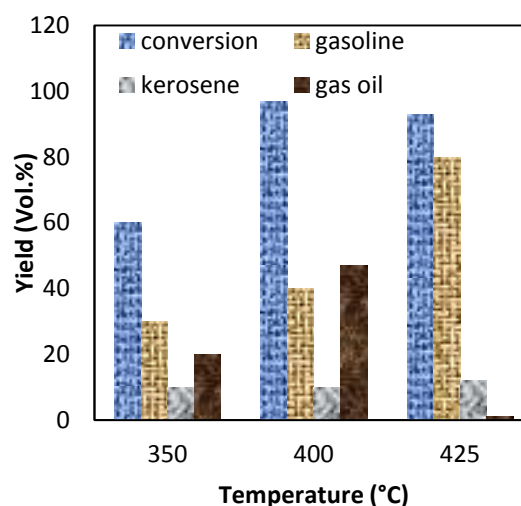
ASTM distillation has been performed to determine the boiling range distribution of the organic hydrocracked product and also to elucidate the amount of the unconverted oil and that transformed to biofuel (Table 3). The fractions of the individual fractions in the produced biofuel at different reaction temperature are represented in Figure 4.

Table 3: Distribution of the hydrocracked products obtained at various temperatures; pressure: 2.5 MPa, LHSV: 5 hr⁻¹, and H₂/ feed: 1600 l/l

| Hydrocracked products | 350 °C | 400 °C | 425 °C |
|---------------------------------|--------|--------|--------|
| Total conversion (wt.%) | 61.355 | 99 | 99.035 |
| Hydrocracked product (wt.%) | | | |
| Gases | 2.05 | 2.34 | 2.77 |
| Liquid | 97.95 | 97.66 | 97.23 |
| Water content | 2.07 | 3.30 | 6.63 |
| Oil content | 95.88 | 94.36 | 90.60 |
| Density at 20 °C | 0.8372 | 0.8215 | 0.8125 |
| Kinematic viscosity at 40 °C | 4.8540 | 2.5250 | 1.0496 |
| Sulfur content (ppm) | 0.045 | 0.016 | 0.016 |
| ASTM distillation (vol. %) | | | |
| IBP(°C) | 60 | 50 | 40 |
| 10 | 70 | 70 | 70 |
| 20 | 110 | 110 | 90 |
| 30 | 150 | 140 | 120 |
| 40 | 273.2 | 150 | 130 |
| 50 | 283.9 | 180 | 140 |
| 60 | 305.2 | 273.2 | 150 |
| 70 | - | 294.5 | 150 |
| 80 | - | 305.2 | 150 |
| 90 | - | 305.2 | 250 |
| FBP | 305.2 | 305.2 | 269.7 |
| Recovered (vol.%) | 60 | 97 | 93 |
| Unconverted and residue (vol.%) | 39 | 1 | 1 |
| Loss (vol.%) | 1 | 2 | 6 |
| Biofuel yield (wt.%) | 57.245 | 93.36 | 89.635 |
| Biofuel selectivity (%) | 93.30 | 94.3 | 90.508 |

It is obvious from the figure that the produced petroleum-like fraction composed of 50 vol.% gasoline, 16.7 vol.% kerosene, and 33.3 vol.% gas oil can be obtained at 350 °C, but the yield is unsatisfactory. By increasing the reaction temperature to 400 °C, the major fraction was distilled in the gas oil range and comprised 48.46 vol.% of the produced biofuel, whereas 41.23 vol.% was gasoline and the remainder (10.31 vol.%) represented the kerosene fraction. Upon raising the reaction temperature up to 425°C, relatively lighter products were attained

involving a high percentage of gasoline (86.02 vol.%) associated with some kerosene comprising 12.9 vol.% and an insignificant amount of the heavier gas oil fraction (not exceeding than 1.07 vol.%). This can definitely be attributed to the promotion of the intensive hydrocracking reaction at such a high temperature.

**Figure 4: Distribution of the individual fractions of the biofuel obtained as a function of temperature**

Therefore, the reaction temperature of 400°C possesses the highest selectivity to petroleum-like fraction formation. Moreover, it could be regarded as the most suitable temperature for gas oil production mixed with a considerable amount of gasoline. On the other hand, the best yield of light fraction, particularly gasoline, can be realized at a reaction temperature of 425°C.

Gas Chromatography

In order to investigate the quantity and quality of the hydrocracked products, gas chromatographic analysis was carried out for both the segmented as well as the virgin jojoba oil for comparison.

It is apparent from the GC spectrum of the crude oil that it is principally composed of heavy, straight chain constituents including more than 16 carbon atoms per molecule, particularly in the range of C₄₀-C₄₄ as identified according to the retention time of the recorded peaks

declared in Figure 5a.

The chromatogram of the products obtained after catalytic hydrocracking process, performed at 425 °C, 2.5 MPa hydrogen pressure, and an LHSV of 5 hr⁻¹, is represented in Figure 5b. It is evident from this chart that the peaks corresponding to the high boiling jojoba feed is completely vanished. Instead, lighter components enriched with fragmented molecules including straight and branched chains with lengths less than C₁₆ are detected, indicating the complete splitting of the virgin oil to lighter products. The hydrocracked bio-oil attained is mainly composed of short molecules, which lie in the gasoline range. Furthermore, an appreciable concentration of kerosene fraction is involved. These results are directly compatible with the ones obtained from the distribution of the distillation range of the biofuel, as depicted in Table 3 and Figure 4.

It worth mentioning that an isomerization reaction has also occurred as indicated from the appearance of numerous peaks in the chromatogram (Figure 4b), corresponding to the isomerized molecules. The substantial presence of branched chain components in the product is definitely leading to a significant improvement in the physicochemical properties of the acquired biofuel such as octane number, viscosity, pour point, etc. The promotion of both hydrocracking and isomerization reactions can be undoubtedly imputed to the intrinsic acidity of the used zeolite catalyst.

FTIR Spectra

The FTIR spectra of jojoba oil and the organic liquid product obtained at 425 °C, 2.5 MPa H₂ pressure, a LHSV of 5 hr⁻¹, and an H₂:oil ratio of 1600 l/l are shown in Figure 5a and b respectively.

The spectrum of the virgin jojoba oil appears to be prevalently aliphatic hydrocarbons as evidenced by the appearance of the intense C-H stretching bands of alkane in the 2857-3000 cm⁻¹ region and aliphatic C-H bending of methyl and methylene groups at 1359 and 1459 cm⁻¹

respectively. The observation of an absorption peak at 727 cm⁻¹ suggested the out of plane bending of an alkene. Since jojoba oil is mainly monoalkyl ester, the intense C=O stretching band of the ester appears at 1740 cm⁻¹ and those for the stretching vibration of C-O are observed at 1174 and 1255 cm⁻¹. The FTIR spectrum showed also two weak absorption peaks at 2676 and 3410 cm⁻¹ for the OH of carboxylic acid and the H-bonded of alcohol respectively (Figure 6a).

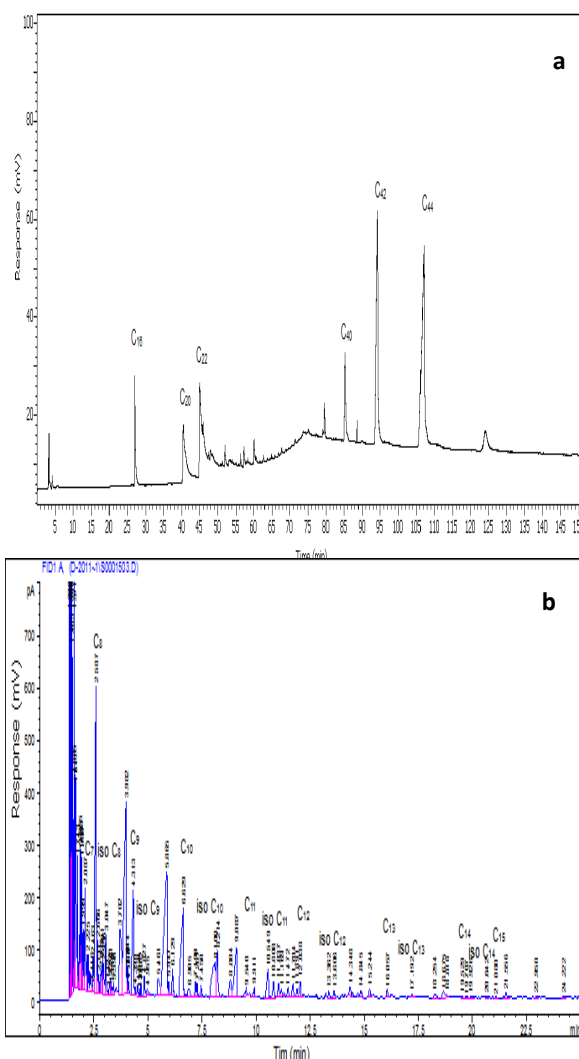


Figure 5: Gas chromatograph for (a) virgin jojoba oil and (b) cracked jojoba oil at 425 °C

The IR analysis, therefore, characterizes the raw jojoba oil as being composed of aliphatic ester, most of which are saturated and associated with some alcohol and carboxylic functional groups.

Figure 6b reveals the IR spectrum of the organic liquid product obtained from hydrocracking of jojoba oil using a zeolite catalyst.

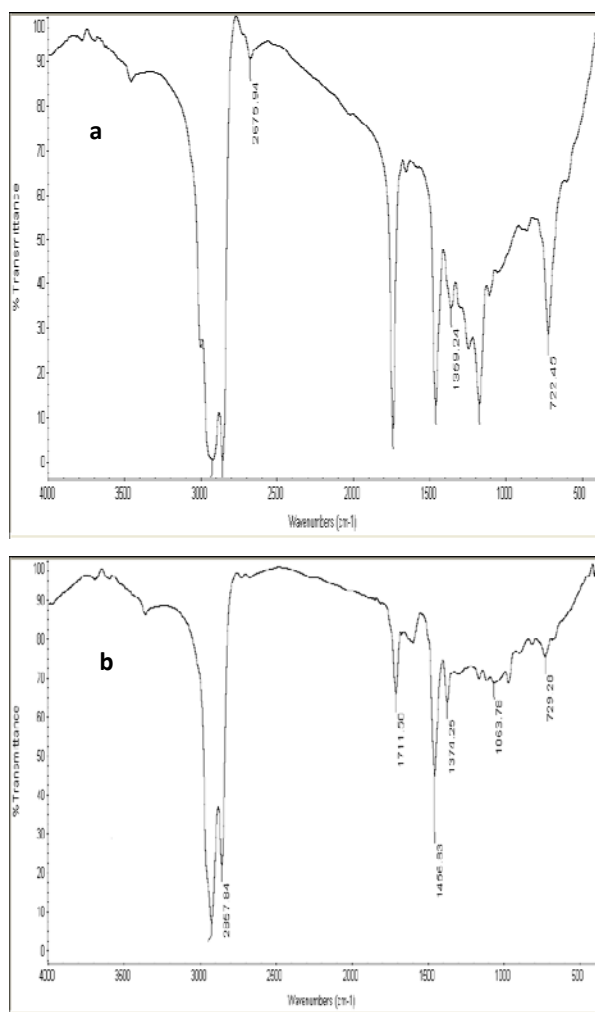


Figure 6: Gas chromatograph for (a) virgin jojoba oil and (b) cracked jojoba oil at 425 °C

The spectrum exhibits absorbance bands associated with saturated C-H stretching vibration (CH-CH₂ and CH₃) at 2858-2924 cm⁻¹. It also shows peaks which are characteristic of aliphatic C-H bending of methylene and methyl groups at 1467 and 1374 cm⁻¹. Therefore, it bears close resemblance to that of the crude jojoba oil; however, there are some main differences between them. It is obvious that the intensity of the stretching bands of C=O at 1711.5 and C-O at 1174 cm⁻¹ are significantly reduced in the cracked spectrum compared to that of jojoba oil with the lack of the absorption

bands of OH group at 2676 cm⁻¹, which can be ascribed to the occurrence of the deoxygenation reaction. In addition, the pronounced diminution of the intensity of the alkene band (C=C out of plane bending vibration at 729 cm⁻¹) confirms the procession of the saturation of the double bond involved in the structure of jojoba molecule.

CONCLUSIONS

It is concluded from this study that:

1. Hydrocracking process is a promising technique for producing biofuel from the nonedible jojoba oil by using zeolite catalysts;
2. The feedstock was entirely converted to hydrocracked products in all conditions under investigation, except at a reaction temperature of 350 °C and 1 MPa hydrogen pressure. Nevertheless, the obtained yield is quantitatively and qualitatively dependant on the applied operating variables;
3. Sufficient high reaction temperatures and hydrogen pressures with a low LHSV are the most appropriate conditions for producing low-boiling petroleum-like fractions and vice versa;
4. It could be deduced from these results that the optimum operating variables, which lead to attaining 93.36 wt.% biofuel are an LHSV of 5 hr⁻¹, an H₂ pressure of 2.5 MPa, and a reaction temperature of 400 °C. The biofuel achieved in these circumstances is mainly composed of a fraction boiled in the gas oil range mixed with a considerable amount of kerosene. Upon raising the reactor temperature to 425 °C, the realized amount of biofuel is slightly diminished to 93 wt.% and is principally comprised of gasoline fraction, i.e. 86 wt%.
5. Petroleum-like fractions resulted from hydrocracking jojoba oil are mainly composed from alkanes as evidenced from the IR

spectra, which indicate a considerable elimination of O₂ from jojoba molecules;

6. As revealed from the GC chromatogram, a significant amount of iso-alkanes are detected, indicating that the isomerization of straight chain paraffins has also taken place along with hydrocracking reaction. Certainly this leads to a consequential improvement in the properties of the produce biofuel.

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