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# INVESTIGATION OF METALLIC OXIDE CATALYST ROLE FOR UP GRADING BIODIESEL TO BIO JET FUEL RANGE HYDROCARBON

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## ABSTRACT

This article investigates the upgrading of biodiesel produced from palm oil using different metallic oxide catalysts under relatively mild conditions. Upgrading experiments were conducted at 300ºC, under pressure (3 bar) for 3 hours using2.5 % catalyst dose (wt. /vol.), at 60 rpm stirring rate in a high-pressure reactor. The employed catalysts are Ni/HZSM5, calcium zinc aluminate, and zinc aluminate. It was found that zinc aluminate ($ZnAl_2O_4$) is an efficient and stable catalyst for cracking long chain hydrocarbons in biodiesel to alkanes. High yield of short chain hydrocarbons were obtained, (50.09%jet fuel, 41.34% diesel fuel range hydrocarbon and zero gasoline range hydrocarbon).The upgraded biodiesel was subjected to elemental analysis and GC mass analyses. In addition, physical properties of upgraded biodiesel like viscosity, density, high heating value (HHV) were determined. It was found that more aromatization and isomerization occurs and increases $C_8$–$C_{15}$ range, which is a jet fuel range hydrocarbons to about 51% using $ZnAl_2O_4$.However, preceding the reaction in the presence of hydrogen for more de-oxygenation resulted about 43% $C_8$ – $C_{15}$.The activity and selectivity of ($ZnAl_2O_4$) for jet fuel range hydrocarbon showed high yield after product distillation process at about 280°C.

**Keywords:** Jet-fuel, bio - oil, catalytic upgrading, cracking.

## 1. INTRODUCTION

Energy shortage and increase in fuel consumption make it must to find alternative sources of bio-fuels to cater these needs [1]. Nowadays the main fuel sources are hydrocarbons, which are depleting. About 79% of energy need all over the world is provided from fossil fuels according to Energy Information Administration (US Energy Information Administration 2009).

Recently bio-fuels have gained international attention as alternative to traditional fuels because they are friendly environment due to their high degradability, no toxicity, and lowharmful emissions [2, 3]. Therefore, it is necessary to search for renewable energy sources to produce sustainable and efficient bio-fuels. Bio - jet fuel can be produced by isomeration of hydrocarbons over different heterogeneous catalyst [4]. One of the most important conversion process to get both fuels and chemical products and converting large bio-oil molecules to short chain hydrocarbons from bio-sources is the thermalcatalyticreaction [5-10]. Thermal cracking of hydrocarbons is performed at 800- 850 ºC [11], while lower cracking temperature produces lower flame temperature that causes elimination of $NO_2$emissions[11].Main constituents of jet-fuel are aromatics and cyclic - hydrocarbons because they are of high energy - density [12].Therefore, it is difficult to produce these constituents using conventional technologies for bio- fuel production without upgrading for further aromatization and isomerization [12].Hydro cracking and isomerization of linear alkanes reduce their molecular weight and increase fuel stability by introducing branching [13,14].

Upgrading of biodiesel can be conducted using different types of catalyst, but heterogeneous catalysts were preferred to avoid the neutralization and separation steps [15-20]. Some of these catalysts like Zinc aluminate, can be regenerated and reused in three reaction cycles with the same activity [21].Zinc aluminates are widely used as a catalyst or support in cracking, aceltylation, trans esterification and dehydrogenation processes [17, 19, 22-25]. This article is investigating upgrading and refining of biodiesel to produce jet fuel using three different types of heterogeneous catalyst that can be easily separated and reused. Catalyst namely Nickel supported acidic Zeolite (Ni- HZSM-5) [12], Zinc Aluminate (Zn $AL_2O_4$) [26], and Calcium addition on Zinc Aluminate (Al-Ca- Zn) [27] were prepared in this work.

## 2. EXPERIMENTAL

### 2.1. Materials

Allmetal nitrates (Zn, Al, Ca, and Ni) and acidic zeolite (HZSM5) are analytical grade. Methanol (99.9%), Potassium hydroxide (98.9%) and Ammonia solution (28wt %) are purchased from EL-Nasr company, Egypt.

### 2.2. Transesterification of palm oil to biodiesel

The biodiesel was prepared using KOH as homogeneous catalyst (0.7%w/v) and methanol (2.5%v/v) with palm oil at 65ºC for 2 hours. Then the produced methyl ester was separated from glycerol, washed with 5% warm acetic acid. Table-1 illustrates the physic-chemical properties of palm oil.

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**Table-1.** Physico chemical properties of palm oil.

| Parameter | Value |
|---|---|
| Viscosity at 40ºC | 41 MPas |
| Density | 0.88 kg/L |
| Acidity | 0.3 mg KOH/g oil |
| Pour point | 3ºC |
| Cloud point | 9ºC |
| C | 71.33wt% |
| H | 21.75wt% |
| O | 5.64wt% |
| N | 0.28wt% |
| S | Nil |
| $<C_5$ (%) | 5.54 |
| $C_5$-$C_7$(%) | 2.4 |
| $C_8$-$C_{15}$(%) | 18.52 |
| $C_{16}$-$C_{19}$(%) | 16.71 |
| $>C_{19}$ (%) | 56.84 |

### 2.3. Catalysts preparation

**Zinc aluminate**

Co-Precipitation method was performed using mixed solutions of zinc nitrate, $Zn(NO_3).6H_2O$ (24gm in 40 ml. distilled water) and aluminum nitrate, $Al(NO_3)_3.9H_2O$(60gm in 40 ml distilled water) [26]. Ammonia solution was added to the previous solution with stirring till complete precipitation. The precipitated gel was filtered, washed with distilled water and dried at 110º C for 24 hours. The dried solid was calcined at 750 ºC for 3.5 hours to obtain zinc aluminate ($ZnAl_2O_4$) catalyst.

**Ni/Zeolite (Ni/HZSM5) catalyst**

Nickel was stabilized by impregnating it on acid zeolite (HZSM5) at 650ºC for 4 hours [12].

**Calcium zinc aluminate**

Co-precipitation method was performed from metal nitrate of Ca, Zn &Al at Ph=8 [27]. The gel obtained was dried and calcined 800˚C for 8 hours.

### 2.4. Experimental set-up

Experimental work was carried on floor-stand reactor under pressure (Parr reactor).The reactor includes stainless steel (316) vessel (3.7 L capacity), pressure gauge and a heating jacket provided with mechanical stirrer. The temperature inside the reactor was controlled by proportional integral derivative panel (PID).

### 2.5. Upgrading process using different solid catalysts

Reaction vessel was charged with 360 ml biodiesel from palm oil and 9 gm catalyst (2.5% w/v), stirred at 65r.p.m for 20 min after passing nitrogen for ten minutes at ambient temperature, then adjusting temperature to (300ºC). The pressure was elevated with the rise in temperature for holding time of reaction (3h). At the end of reaction time, cooling the reactor then collect the reaction mixture. Same previous steps were repeated for the used other two catalysts, and these experimental steps are illustrated in Figure-1.

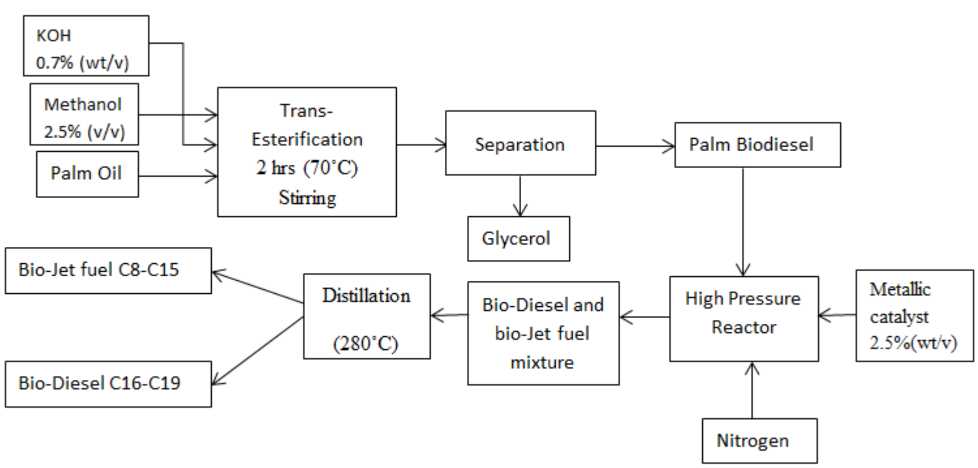


**Figure-1.** Block flow sheet for upgrading process using different solid catalysts

### 2.6 Hydrogenation and distillation of upgraded bio-oil

Same last experimental steps were repeated but with introduction of hydrogen to the reactor after air removal by passing nitrogen then preceded the rest of the experiment. Upgraded bio-oil was distilled using a distillation unit to separate jet fuel ($C_8$-$C_{15}$) as a distillate and diesel ($C_{16}$-$C_{19}$) as a bottom product using 265 ml of upgraded oil at certain temperature.

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## 3. RESULTS AND DISCUSSIONS

### 3.1 Preparation of biodiesel

The palm oil is transesterified using20% (v/v) of methanol and 0.7% (wt. /v) of KOH. The palm biodiesel is produced from transesterification process in addition to glycerol as a by- product. Table-2 illustrates Physico chemical properties of palm biodiesel.

### 3.2Pressure and temperature profiles inside the reactor

Figures 2 and 3 show the pressure and temperature profiles during upgrading of the biodiesel inside the high-pressure reactor. Heating-up takes around 100 min then the pressure remains constant around 3.3bars for about 180 min thereafter. The average temperature was300˚C and the average pressure are 3.3 bars. The pressure and temperature throughout all experiments were oscillating around the same value, which indicates that the upgrading results are just an indication of the catalyst effect.

**Table-2.** Physico chemical properties of palm biodiesel.

| Parameter | Value |
|---|---|
| Viscosity at 26.5ºC (M Pas) | 9.97 |
| Density at 15ºC ( Kg/L) | 0.925 |
| Cloud point (ºC) | 13 |
| Pour point ( ºC) | 9 |
| C (%) | 68.92 |
| H (%) | 21.88 |
| O (%) | 8.6 |
| N (%) | 0.601 |
| S (%) | Nil |
| $<C_5$ (%) | 0 |
| $C_5$-$C_7$ (%) | 0.07 |
| $C_8$-$C_{15}$ (%) | 6.79 |
| $C_{16}$-$C_{19}$ (%) | 92.78 |
| $> C_{19}$ (%) | 1.06 |
| HHV (MJ/Kg)[(28)] | 43.57 |

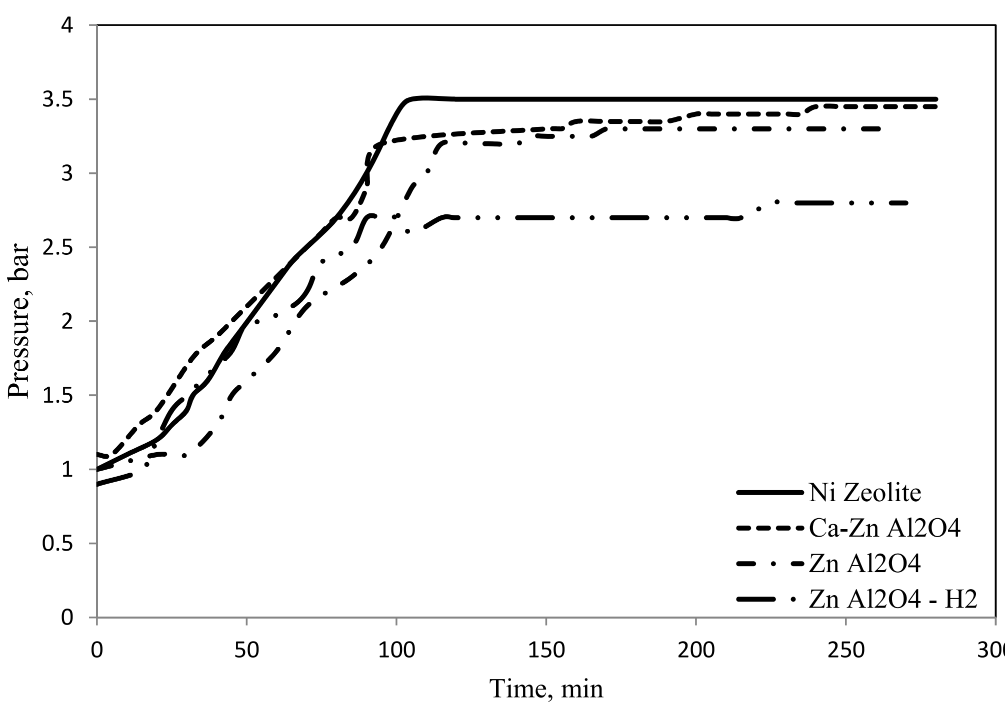


**Figure-2.** Pressure inside reactor during the upgrading experiment.

### 3.2. Upgrading of palm biodiesel

The composition of palm biodiesel is mostly diesel range hydrocarbon $C_{16}$-$C_{19}$ as shown in Table-2. To upgrade the produced biodiesel, the biodiesel is subjected to cracking reaction using different catalysts at 300˚C under a pressure of 3.3 bars; the detailed flow sheet is

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shown in Figure-1. The products from cracking are shown in Table-3, noting that the best results from cracking is represented using ($ZnAl_2O_4$) catalyst.

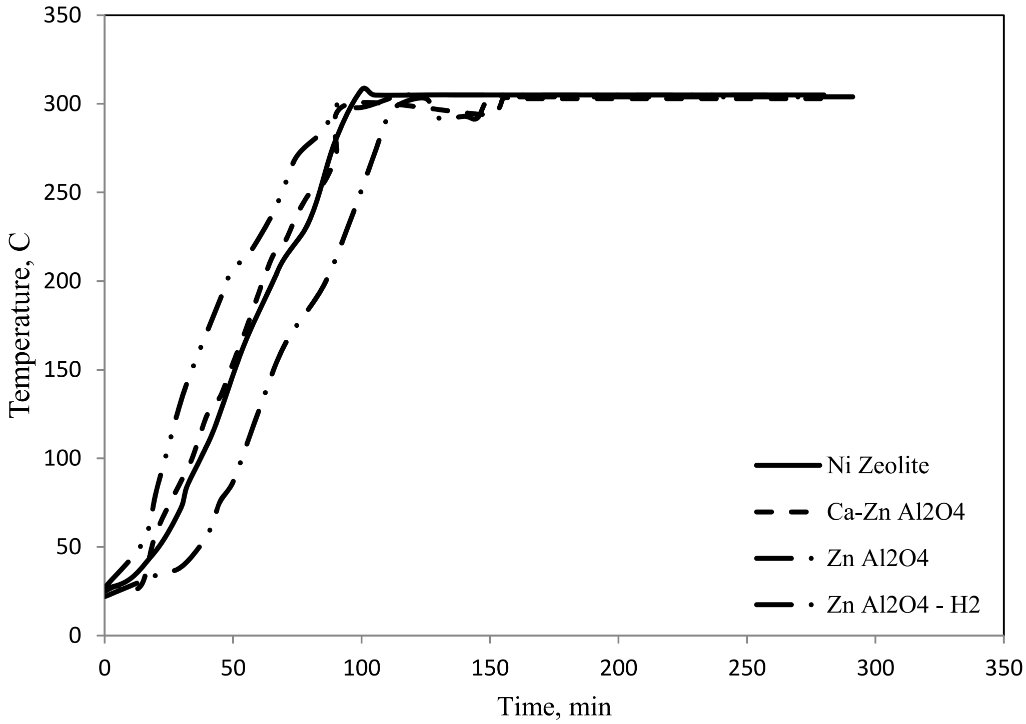


**Figure-3.** Temperature profile inside the Parr reactor during the upgrading experiment.

**Table-3.** Composition of range hydrocarbon from GC-Mass of upgraded biodiesel using different catalysts.

| catalyst / composition | Ni/Zeolite | $CaZnAl_2O_4$ | $ZnAl_2O_4$ without hydrogen | $ZnAl_2O_4$ with hydrogen |
|---|---|---|---|---|
| <$C_5$ % | 0 | 0 | 0 | 0.05 |
| $C_5$-$C_7$% | 0 | 0 | 0 | 0.05 |
| $C_8$-$C_{15}$% | 15.97 | 50.09 | 47.08 | 43.26 |
| $C_{16}$-$C_{19}$% | 79.17 | 41.34 | 44.88 | 23.78 |
| > $C_{19}$% | 5.2 | 8.56 | 8.59 | 32.87 |

Noting that $C_5$ - $C_7$ are the main composition for gasoline range alkanes while $C_8$ - $C_{15}$ are main constituents of jet fuel range alkanes and $C_{16}$-$C_{19}$ are components of diesel range alkanes [4]. Table (4) represents the results of distillation products from cracking experiments using $ZnAl_2O_4$ as a catalyst with and without hydrogen. From the results in Table-3, it is clear that: percent of $C_{16}$ - $C_{19}$ (biodiesel range alkanes) decreases from 92.78% of palm biodiesel by up-grading without hydrogenation to 79.17%, 41.34% and44.88% using Ni/Zeolite, $CaZnAl_2O_4$ and $ZnAl_2O_4$ catalyst respectively then to 23.78by using $ZnAl_2O_4$ with hydrogenation.

From Table-4 it is clear that the percent of biodiesel range alkanes $C_{16}$-$C_{19}$% was reduced to 23.78% and 10.53% after distillation of up-gradedproductusing $ZnAl_2O_4$ catalyst with and without hydrogenation respectively. All the results indicated that biodiesel after treatment with different catalyst is converted partially to jet fuel and distillation has efficient performance to improve quality of refined biodiesel (deep hydro de-oxygenation), which means that distillation of biodiesel has produced a distillate containing 92.55%, $C_8$-$C_{11}$, and $C_{16}$ - $C_{19}$ decreased to 10.53% using $CaZnAl_2O_4$ as catalyst at 280ºC.? While using hydrogen in the reaction (HDO), $C_{16}$ - $C_{19}$content decreased to 23.78% as shown in Figure-4.

**Table-4.** Composition of range hydro carbon from GC-Mass of distillated upgraded biodiesel using catalysts ($ZnAl_2O_4$) with & without hydrogen.

| composition | Distillate $ZnAl_2O_4$ without hydrogen | Distillate $ZnAl_2O_4$ with hydrogen |
|---|---|---|
| <C5 % | 0 | 0.096 |
| C5-C7% | 0 | 2.19 |
| C8-C15% | 88.94 | 46.63 |
| C16-C19% | 10.53 | 14.25 |
| > C19% | 2.12 | 38.68 |

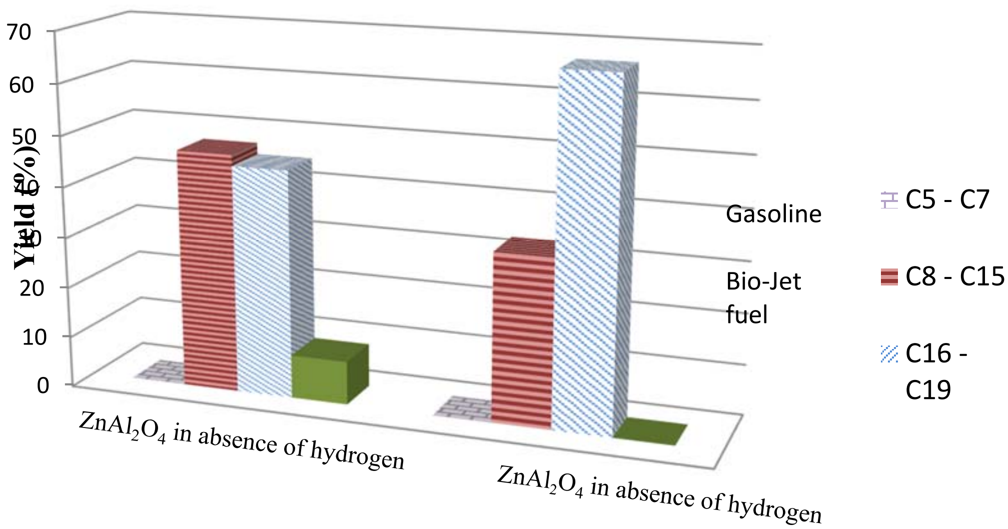


**Figure-4.** Diesel Jet fuel and Gasoline range hydrocarbon via $ZnAL_2O_4$ catalyst with/without hydrogen.

Results of elemental analyses are illustrated in Table-5, from which it is clear that by comparing oxygen content, distillation of upgraded biodiesel without hydrogen decreased sharply from 8.31% to 0.24.

Modified Dulong equationis used to calculate the higher heating value [28]:

$$HHV = 4.18 * (78.4 * C + 241.3 * (H - O/8) + 22.1 * S)$$

**Table-5.** Elemental analyses and Higher Heating Values (HHV) of biodiesel and upgraded bio-oils using different catalysts.

| Composition (wt. %) | Palm oil | Biodiesel of palm oil | Upgrading (Ni/Zeolite) | Upgrading ($ZnAl_2O_4$) | Upgrading $CaZnAl_2O_4$ | Distillate of upgrading ($ZnAl_2O_4$) without hydrogen | Upgrading ($ZnAl_2O_4$) with hydrogen | Distillate upgrading ($ZnAl_2O_4$) with hydrogen |
|---|---|---|---|---|---|---|---|---|
| C | 67.13 | 68.92 | 62.61 | 62.41 | 60.41 | 70.71 | 60.61 | 69.33 |
| H | 24.95 | 21.88 | 28.32 | 29.02 | 30.02 | 28.8 | 29.25 | 20.75 |
| O | 7.64 | 8.6 | 8.74 | 8.31 | 9.1 | 0.25 | 9.58 | 9.44 |
| N | 0.28 | 0.6 | 0.33 | 0.26 | 0.47 | 0.24 | 0.56 | 0.48 |
| S | NIL | NIL | NIL | NIL | NIL | NIL | NIL | NIL |
| C/H | 2.6905862 | 3.149992 | 2.210885 | 2.150585 | 2.012325 | 2.455 | 2.07213 | 3.34120 |
| HHV (28) (MJ/Kg) | 42.9738 | 43.570 | 47.98 | 48.675 | 48.93 | 52.19 | 48.16 | 42.46 |

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Three catalysts used for upgrading were Ni/HZSM-5, $CaZnAl_2O_4$, and $ZnAl_2O_4$. A better performance is observed with $CaZnAl_2O_4$ and $ZnAl_2O_4$, similar performance has been observed for both catalysts. Comparing C/H weight ratios we notice that using $ZnAl_2O_4$ as catalyst gave C/H ratio less than that of crude palm biodiesel or that for biodiesel upgraded using Ni/HZSM5. Which indicate that the product of upgrade biodiesel via $ZnAl_2O_4$ was not only aromatic compound but more saturated alkanes since aromatic product resulting from the decrease of acid sites on the surface of the catalyst [12]?

**3.3. Distillation of upgraded biodiesel**

The distillation column is used to separate jet fuel ($C_8$-$C_{15}$) as a distillate and diesel ($C_{16}$-$C_{19}$) as a bottom product at 280-300˚C. Starting with 265 ml of upgraded biodiesel, a distillate of around 56% is produced containing 87% of jet fuel ($C_8$-$C_{15}$). From GC-Mass it was found that the major constituents of jet fuel hydro carbon range ($C_8$-$C_{15}$) were paraffinic compounds 95.5% while cyclic and aromatic constituents were 3.5% and 1% respectively which is a good agreement with previous studies[29].

A bottom product of 44% is produced containing diesel ($C_{16}$-$C_{19}$).The results have indicated that bio-jet fuel can be produced using $ZnAl_2O_4$ as a catalyst under mild reaction conditions and using a distillation column to separate the required range hydrocarbon. This work represents a successful application of bio-refinery to produce jet fuel range.

**4. CONCLUSIONS**

- Very promising results were obtained using zinc aluminate ($ZnAl_2O_4$) as catalyst in upgrading palm biodiesel to Jet-fuel.
- The reduction in viscosity indicates that water content is also reduced which leads to increase in HHV.
- Ni/HZSM-5 produced less bio-aviation range hydrocarbons when it is used to upgrade palm biodiesel.
- Loading calcium mass on zinc aluminatedo not improve obviously the bio-jet hydrocarbon range.
- The produced hydrocarbon via zinc aluminate as catalyst was mainly branched alkanes and cyclo-alkanes with a maximum yield ≈89% after upgrading and distillation processes.
- Distillation of upgraded biodiesel without hydrogenation had efficient performance to improve quality of refined biodiesel.

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**REFERENCES**

[1] Anjani R.K. Gollakota. Madhurima Reddy.Meddy D. Subramanyam.Nanda Kishore. 2016. A review on the upgradation techniques of Pyrolysis oil Renewable and Sustainable Energy Reviews. 58: 1543-1568.

[2] Al Zuhair S. 2007. Production of biodiesel: possibilities and challenges. Biofuels Bioproducts and Biorefining. 1(1) 57-66, ISSN: 1932-103.

[3] Vicente G., Coteron A., Martinez M. and Aracil J. 1998. Application of the factorial design of experiments and response surface methodology to optimize biodiesel production. Industrial Crops and Products. 8(1): 29-35, ISSN 0926-6690.

[4] Siyang Liu, Qingqing Zhu, Qingxin Guan, Liangnian He, Wei Li. 2015. Bio - aviation fuel production ffromhydroprocessing castor oil promoted by the nickel – based bifunctional catalysts. Bioresource Technology. 183: 93-100.

[5] Li Xiao-hua, CHEN Lei, FAN Yong- sheng, JIAO Li-hua, Sha, CAI Yi-XI. 2015. Study on preparation of refined oil by upgrading of pyrolytic vapors using Zn-p/ HZSM-5 zeolite. Journal of Fuel Chemistry and Technology. 43(5).

[6] Zhang Q, Chang J. Wang T j, Xu Y. 2007. Review of biomass Pyrolysis oil properties and upgrading research. Energy Convers Manage. 48(1): 87-92.

[7] Zhu X F, Lu Q. 2014. The principle and technology of biomass Pyrolysis. Beijing: Science Press.

[8] Du Y. Hu C W. 2007. Future of Pyrolysis obbiomass. J. ShanxiUniv (Nat Sci Ed). 21(2): 76-80.

[9] Shen D K,Liu G F, Zhao J, Xue J T, Guan S P,Xiao R. 2015. Thermo- chemical conversion of ligning to aromatic compounds: Effect of lignin source and reaction temperature. J. Anal Appl Pyrolysis. 112: 56-65.

[10] Liu W W, Hu C W, Yang Y, Zhu L F, Tong D M. 2010. Effect of the interference instant of zeolite HY catalyst on the Pyrolysis of pubescens. Chin J Chem Eng. 18(2): 351-354.

[11] S.M.Sadrameli, Alex E, S, Green. 2007. Systematics of renewable olefins from thermal cracking of canola oil. J.Anal, Appl. Pyrolysis. 78: 445-451.

[12] YujingWeng, SongbaiQiu, Longlong Ma, Qiying Liu, Mingyue Ding, Qian Zhang, Qi Zhang and Tiejun Wang. 2015. Jet - Fuel Range Hydrocarbons from Biomass- Derived Sorbitol over Ni- HZSM-5/SBA-15 Catalyst. Catalyst. 5: 2147-2160.

[13] Wang T, Qiu S, Chen L, Liu Q, Long J, Tan J, Zhang Q, Zhang Q, Zhang Q, Ma L. 2015. Liquid fuel production by aqueous phase catalytic transformation of biomass for aviation. Appl. Energy. 160: 329-335.

[14] Kim Y.T.; Dumesic J.A, Huberm G.W. 2013. Aqueous - phase hydride oxygenation of sorbitol: A comparative study of Pt/Zr phosphate and PtReOx/ C.J. Catal. 304: 72-85.

[15] Y.C.Sharma, B. Singh, J.Korstad. 2011. Advancements in solid acid catalyst for ecofriendly and economically viable synthesis of biodiesel, biofuels, Bioproducts and Biorefining. 5: 69-92.

[16] Y.C.Sharma, B.Singh, J.Korstad. 2010. Application of an efficient nonconventional heterogeneous catalyst for biodiesel synthesis from pongamia oil. Energy & Fuels. 24, 3223-3231.

[17] V.Pugent, S.Maury, V.Coupard, A.Dandeu, Anne - AgatheQuoineaud, Jean - Louis D.T.Bonneau. 2010. Stability activity and selectivity study of a zinc aluminate heterogeneous catalyst for the transesterification of vegetable oil in bath reactor. Applied catalystA: General. 374: 71-78.

[18] Y.C.Sharma, B.Singh, J.Korstad. 2011. Latest developments on application of heterogeneous basic catalysts for an efficient and ecofriendlysynthesis of biodiesel: a review. Fuel. 90: 1309-1324.

[19] S.Farhadi, S.Panahandehjoo. 2010. Spinel – type zinc aluminate (ZnAL2O4) nanoparticles prepared by the co-precipitation method: a novel green and recyclable heterogeneous catalyst for the acetylation of amines, alcohols and phenols under solvent free conditions. Applied Catalysis A: General. 382: 293-302.

[20] Wrzyszcz, M. Zawadzki, J. Trawczynski, H. Grabowska, W, Mista. 2001. Some catalystic properties of hydrothermally synthesized zinc aluminate spinel. Applied Catalysis A: General. 210: 263-269.

[21] C.T. Alves, A. Olivera, S.A.V.Carneiro, A.G.Silva, H.M.C. Andrade, A.A.B. Vieira de Melo, E.A. Torres. 2013. Transesterification of waste frying oil using a zinc aluminate catalyst. Fuel processing Technology. 106: 102-107.

[22] R. Othaman, N. Aziz, W.J.N. Fernando, J.Kim. 2009. Technology for production of biodiesel focusing on green catalytic techniques: a review. Fuel processing Technology. 90: 1502-1515.

[23] II-HO Choi, Kyung - Ran Hawang, Jeong - Sik Han, Kyong - Hwan, Ji Sun Yun, Jin- Suk Lee. 2015. The direct production of jet - fuel from non-edible oil in a single - step process. Fuel. 158: 98-104.

[24] Hermida L, Abdullah AZ, Mohamed AR. 2015. Deoxygenation of fatty acid to produce diesel – like hydrocarbons: a review of process conditions, reaction kinetics and mechanism. Renew Sustain Energy Rev. 42: 1223-33.

[25] M.Kim, S.Yan, S.O.Salley, K.Y.S.Ng. 2009. The effect of sodium on the catalytic activity of ZnO – AL2O3/ZSM-5 AND SnO-AL2O3/ZSM-5 for the transesterification of vegetal oil with methanol. Catalysis Communications. 10, 1913-1919.

[26] Suellen Battiston, Caroline Rigo, Eric da Cruz Severo, MarcioAantonioMazutti. 2014. Synthesis of Zinc Aluminate (ZnAL2O4) Spinel and its Application as Photocatalyst. Materials Research. 17(3): 734-738.

[27] M,A,Valenzuela, G.Aguilar, P.Bosch, H.Armendariz, P.Salas and A.Montoya. 1992. Effect of calcium addition on zinc aluminate spinel. Catalysis Letters 15: 179-188.

[28] K. Bousdira, L. Nouri, J. Legrand, Y. Bafouloulou, M. Abismail, H. Chekhar and M. Babahani. 2014. An overview of the chemical composition of phoenicicole biomass fuel in Guerraraoasis. Revue des Energies Renouvelables SIENR’14 Ghardaïa. pp. 99-108.

[29] Johnathan Holladay. 2015. Jet fuel advances in bio-oil and alcohol upgrading. Sustainable alternative aviation fuels workshop.