

RESEARCH ARTICLE

DEVELOPMENT OF $Mg-SO_4^{2-}/ZrO_2$ HETEROGENEOUS CATALYST FOR TRANSESTERIFICATION REACTION OF RICE BRAN OIL

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ABSTRACT

We have studied transesterification of Rice bran oil with heterogeneous catalyst and found that the heterogeneous catalyst $Mg-SO_4^{2-}/ZrO_2$ worked very well for transesterification of oils. The maximum conversion was above 90% at Temperature 80°C and the GCMS analysis of biodiesel showed that the biodiesel consisted of ten major products viz. Methyl Palmitate, Methyl Stearate, Methyl Oleate, Methyl Linolenate, Methyl Linoelate, Methyl Eicosanolate, Methyl Archidate, Methyl Tetra deconate, Methyl Pentyl hexonate and Methyl Behenate. The first order plots were found to be fit the conversion versus time data. Along with this yield of different components of the biodiesel versus time data showed the reaction is first order. It is also found that the value of rate constant approximately 1 min⁻¹. We have also proposed the reaction mechanism of biodiesel formation and explain with the results. The catalyst was characterized by FTIR, TGA, BET and SEM and we used this catalyst continuously for 1000 hours of reaction time without effecting conversion and yield which shows the catalyst activity remained unchanged at least for 1000 h. Therefore this catalyst can be used to produce biodiesel at industrial scale.

Key Words: Transesterification, Rice bran oil, Biodiesel, Supported Zirconia, Heterogeneous Catalyst.

INTRODUCTION

The conventional energy sources like petroleum, coal, natural gas are very limited. At the usage of this rate that fossil fuels will be consumed very soon. And increasing use of fossil fuel is also polluting the air and increasing the global warming effect due to emission of carbon dioxide. Due to these reasons, the use of biodiesel for fuel has now become economical, in some countries, it has become mandatory to mix it with regular diesel in about 5-10%. In addition to becoming economical in some cases it has positive environmental impacts. This is because they have higher cetane number which gives shorter ignition delay. For its use for period of time, the emission has lower particulate matters giving longer minimum carbon deposits on injector. Homogenous base-catalyzed transesterification of oils (or triglycerides) are mostly used method for the biodiesel production. In spite of all advantages, this technology requires rigorous control of raw materials; the raw material must have very limited presence of water and no free fatty acids (FFAs). This is because presence of water and FFA leads to saponification and the soap formation which reduces the formation of biodiesel. In the production of biodiesel, glycerol is the main byproduct and it increases difficulties of separation of glycerol is emulsified. We have reviewed the current literature on the selection of heterogeneous catalyst so that these difficulties can be overcome. It was observed that in the reaction mass, there exists a water layer having glycerol and organic layer consisting of biodiesel and the solid layer has the catalyst. Due to formation of slight amount of soap, the powdered catalyst tends to be entrained and is carried away with the product layer

hence giving the loss of the catalyst. In view of this difficulty, the literatures show the absence of true heterogeneous catalyst which could be repeatedly recycled. An alternate route of biodiesel production could be esterification of free fatty acid by acid catalyst. This reaction may occur in the presence of triglycerides or conjugated with transesterification reaction. Since the free fatty acids are the reactants of esterification hence no limit of FFA is bonded. In addition of this, there exists raw material such as used oil and beef tallow oil without need of neutralization. In such reaction, soap is not formed since the catalyst is not base and separation of glycerol is avoided. In view of this, we study a review of heterogeneous catalysts for esterification reaction [1-26]. Various catalysts suggested are Montmorillonite clay (Kawabata *et al.*, 2003), hydrotalcite clay (Zatta *et al.*, 2011), cation exchange resin (Park *et al.*, 2010;), (Peters *et al.*, 2006), (Marchetti and Errazu, 2008), (Marchetti *et al.*, 2008), (Tsai *et al.*, 2011), (Yadav and Thathagar, 2011), nano-magnetic solid catalyst (Shengyang Hu *et al.*, 2011), metal oxides (Mello *et al.*, 2011), (Sarkar *et al.*, 2010), (Kim *et al.*, 2011), Heteropoly acids (HPAs) (Park *et al.*, 2010), (Sarkar *et al.*, 2010), (Rafiee *et al.*, 2008), (Bhorodwaj and Dutta, 2011) and zeolites (Sejidov *et al.*, 2005), (Marchetti and Errazu, 2008), (Sarkar *et al.*, 2010), (Miao and Shanks, 2011) and The picolinic acid modified 12-tungstophosphoric acid (PA-HPW) can be easily recovered and reused (Shu-wen Gong *et al.*, 2014) etc. From the literature; it is found that catalysts have low the reusability. It is also found that the catalytic activities of all catalysts are relatively slow and temperature needed to operate between 100- 200°C. There are few reactions that occur at temperatures less than 100°C as in reference (Park *et al.*, 2010), (Peters *et al.*, 2006), (Marchetti *et al.*, 2008), (Sarkar *et al.*, 2010), (Miao and Shanks, 2011) and (Niasari *et al.*, 2005; Rattanaphra *et al.*, 2011; Bhorodwaj and Dutta, 2011; Shu-wen Gong *et al.*, 2014; Borges and Diaz, 2012; Liu *et al.*, 2013; Meng *et al.*, 2013

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Ramos *et al.*, 2014; Xie and Zhao, 2014). In this paper we report heterogeneous catalyst which can be recycled for long number of cycles. We used three supports viz. modified alumina, hydrotalcite clays and Raney nickel support and out of these the modified alumina served the best with HPA catalyst. The oil tested was rice bran oil (10.56 % FFA).

Experimental Section

Material used

The crude Rice bran oil is purchased from New Market, Bhopal. Zirconium Oxychloride and Magnesium nitrate extra pure were purchased from Loba Chemie, Mumbai and used as received. Methanol and liquor Ammonia (10%w/v) were obtained from Central Drug House, New Delhi and used as received.

Preparation of catalyst

Preparation of support

To prepare the support, 20g of hydrated zirconyl oxychloride $ZrOCl_2$ were dissolved in about 100 ml of deionized water and a drop wise addition of aqueous solution of ammonia resulted in the precipitation. A necessary amount of ammonia solution was added so that the pH value could be adjusted to be approximately in range of 9–12. The precipitate was aging for 3h in water bath at 100°C , filtered by vacuum and washed several times until a negative test of chloride ion was achieved and then dried for about 12 h at 120°C . Then it is calcined at 500°C for 3 h. the final product is named as zirconium dioxide.

Preparation of supported catalyst

Sulfated zirconia was prepared by wet impregnation method of 4g of ZrO_2 with 60 ml aqueous solution of 1N sulfuric acid for 8 h with occasional stirring. The solution was then filtered and the obtained materials were dried at 110°C for 12 h. The catalyst was calcined at 500°C for 3 h. The resulting materials were designated as sulfated zirconia. Magnesium doped sulfated zirconia was prepared by sequential impregnation method. Sulfated Zirconia was impregnated by grinding with magnesium nitrate with addition of 1-2ml of H_2O . then the final solid was dried at 110°C for 12h and calcined at 500°C for 3h. The final catalyst is designed as magnesium doped sulfated zirconia ($Mg-SO_4^{2-}/ZrO_2$).

Catalyst Test

Reaction Procedure

A round bottom flask (500ml) with water- cooled reflux condenser arrangement was used as laboratory-scale reactor for the experimental studies in this work, and a hot plate with magnetic stirrer was used for heating the mixture in the flask. For the simultaneous transesterification and esterification reaction of oil, the mixture was stirred at the same agitation speed of 1000 rpm for all the test runs. The reactor was initially charged with 100 ml oil, 2g of catalyst and heated to 50°C then methanol (30 ml) is added drop wise and further it is heated to the required temperature ($60-80^\circ\text{C}$) before running the reaction for desired reaction time (1-10h). An on/off controller was used for controlling the temperature with a chrome alloy thermocouple for temperature sensing. The reaction mixture was withdrawn after the desired reaction time by stopping the reaction and reaction mixture was collected through a separating funnel. It has the two layers, the first being methyl ester, oil and methanol and second is glycerol. The third phase is solid catalyst at the bottom of the reactor. The upper layer is collected and heated up to 60°C to removes methanol from the methyl ester and oil mixture. Now conversion is determined by the following procedure 1 ml of mixture is added to 40ml of alkali (NaOH, 0.1N) and reacted for 12h. After completion of the reaction, the sample was titrated with H_2SO_4 (0.1N) to get the percentage of esters in the upper layer (Shu-wen Gong *et al.*, 2014). Where Above, V_B is volume o H_2SO_4 required for titration of Biodiesel sample (ml), V_O is volume of H_2SO_4 required for titration of blank oil (ml), N is Normality of acid and MW_{ME} Molecular weight of the ester, which is approximately taken as 292.20 assuming it is methyl ester of lauric acid. The products obtained after reaction were also analyzed by gas chromatography (GC) using a HPINNO-Wax capillary column $0.25\text{mm} \times 60\text{m}$ film thickness 0.20 micron with flame ionization detector. The components of the biodiesel were analyzed by using a Shimadzu QP-2000 GCMS.

RESULTS AND DISCUSSION

Characterization of the final Catalyst

FTIR Analysis of Catalyst: The loading of the $Mg-SO_4^{2-}/ZrO_2$ on the support has been confirmed by the FTIR of the catalyst.

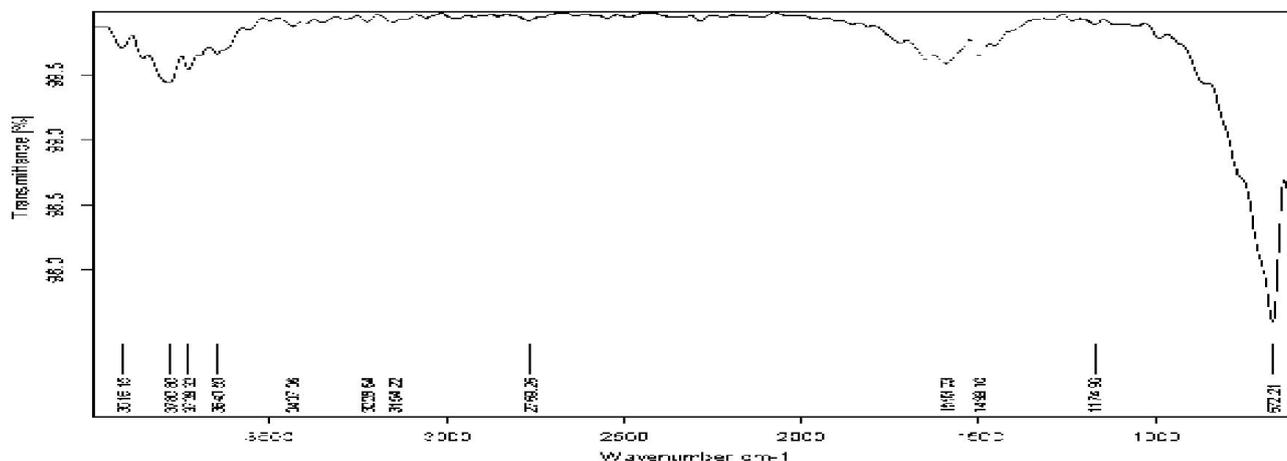


Fig. 1. FT-IR image of $Mg-SO_4^{2-}/ZrO_2$ catalyst

Scanning Electron Microscopy of the catalyst

SEM of final catalyst, magnesium doped sulfated zirconia has been shown in fig. 2.

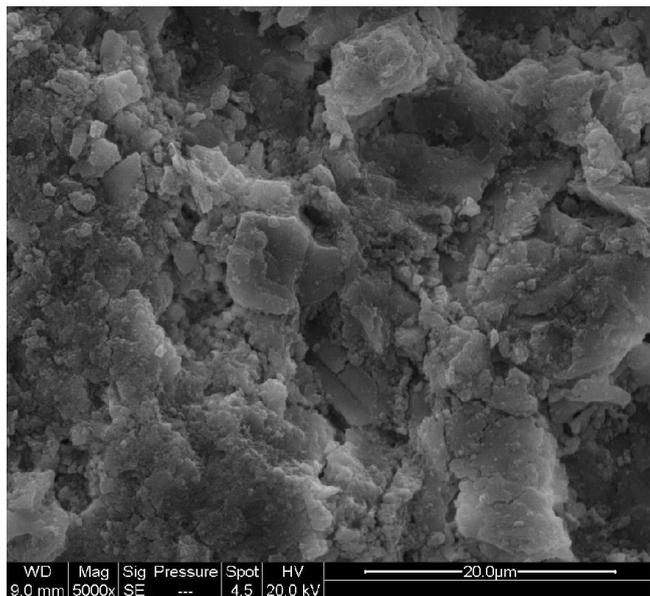


Fig. 2. SEM image of Mg-SO₄²⁻/ZrO₂ catalyst

Thermogravimetric analysis (TGA) of Mg-SO₄²⁻/ZrO₂

The TGA analysis of the complex catalyst was carried out using a Perkin –Elemer instrument in N₂ atmosphere. The TGA graphs of Mg-SO₄²⁻/ZrO₂ catalysts are given in figure 3. About 10-15 mg of the sample (Mg-SO₄²⁻/ZrO₂) was taken and heated from 40° C to 950°C at the rate of 10°C/min and the weight loss was measured in this temperature range. The catalyst showed considerable weight loss (more than 35%) on heating till 250°C while the corresponding catalysts is found to be stable till 500 °C.

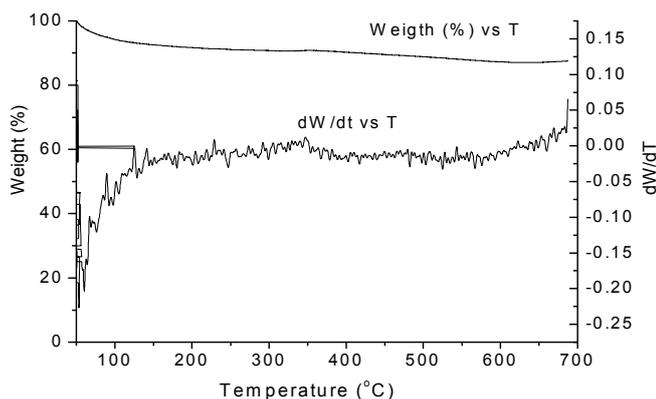


Fig. 3. TGA image of Mg-SO₄²⁻/ZrO₂ catalyst

Surface area Analysis

The surface area (SA) of the catalyst at various stages of the catalyst preparation has been measured on a Coulter SA 2100 instrument and is analyzed by the BET method. The surface area of the Mg-SO₄²⁻/ZrO₂ was found to be 226m²g⁻¹. We ran our experiments at reactor size of 200ml as well as 20 liter batch reactor and the oil conversion data were not found to be affected by the reactor size which signifies that the overall reaction remains in reaction kinetics controlled regimes and is

independent of diffusion. The reaction product could be easily separated in a settling tank by leaving it over night and the biodiesel layer separated from the glycerin phase. The product formed was separated and subjected to GCMS analysis using GC column HPINNOWAX and the product was shown to consists of ten major constituents which are given below. Methyl Palmitate, Methyl Stearate, Methyl Oleate, Methyl Linolenate, Methyl Linoelate, Methyl Eicosanone, Methyl Archidate, Methyl Tetra deconate, Methyl Pentyl hexonate, and Methyl Behenate.

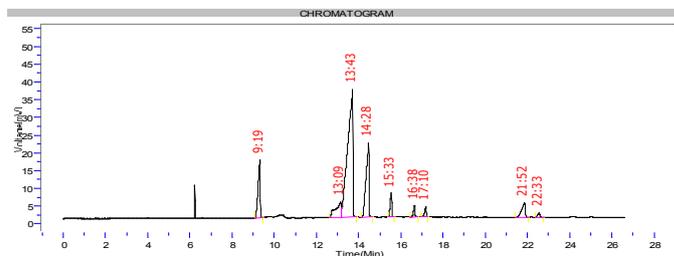


Fig. 5. Chromatogram of Biodiesel produced by using Mg-SO₄²⁻/ZrO₂

Conversion and Yield Graphs for Rice bran oil

The reaction results of transesterification of oil are given in fig. 6 and for their components of Rice bran oil given in fig.7-14.

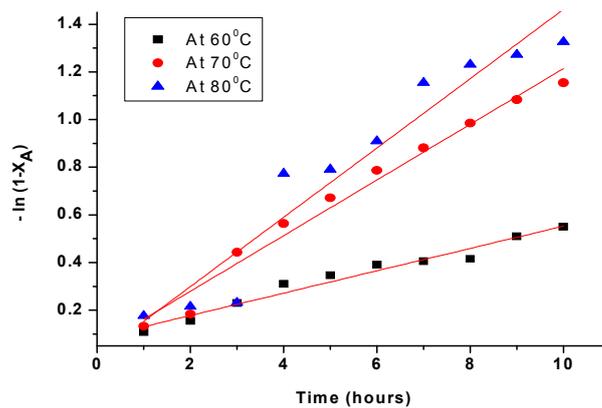


Fig. 6. Conversions for Rice Bran Oil

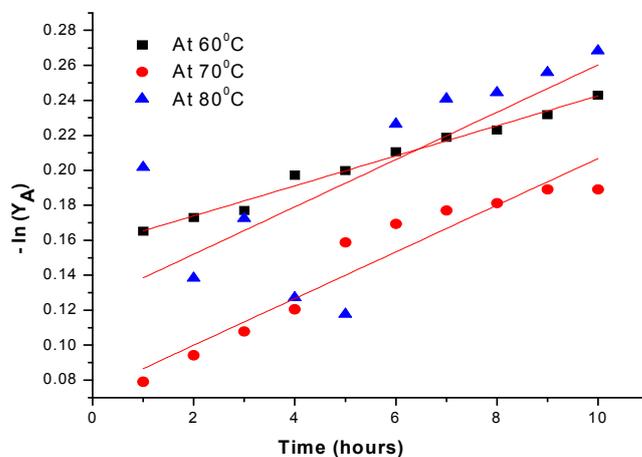


Fig. 7. Yield for the Methyl Palmitate in Biodiesel Obtained From Rice Bran Oil

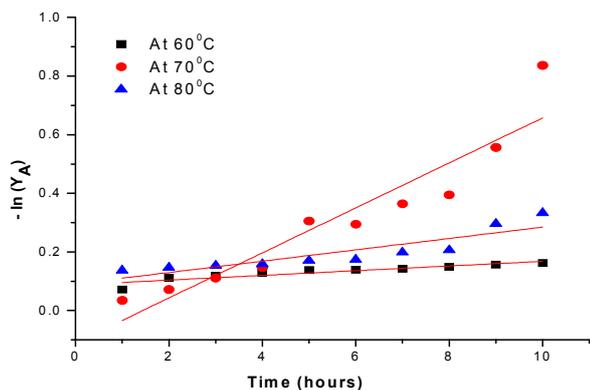


Fig. 8. Yield for the Methyl Stearate in Biodiesel Obtained from Rice Bran Oil

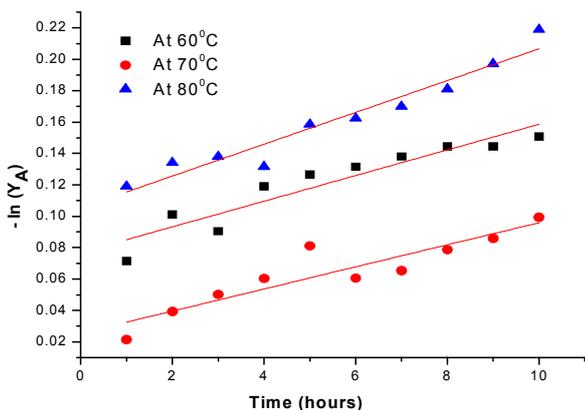


Fig. 9. Yield for the Methyl Oleate in Biodiesel Obtained from Rice Bran Oil

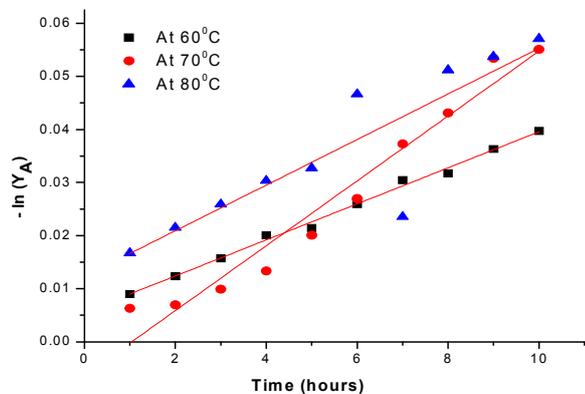


Fig. 10. Yield for the Methyl Linolenate in Biodiesel Obtained from Rice Bran Oil

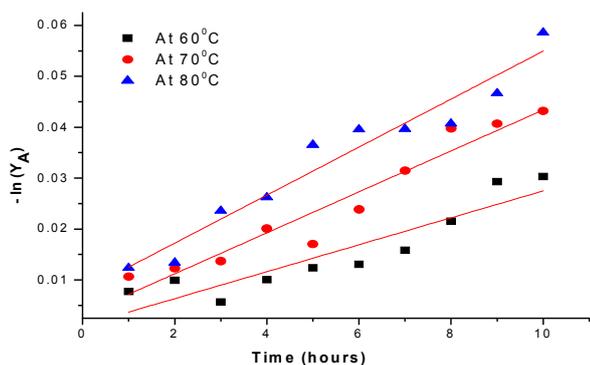


Fig. 11. Yield for the Methyl Eicosanolate in Biodiesel Obtained from Rice Bran Oil

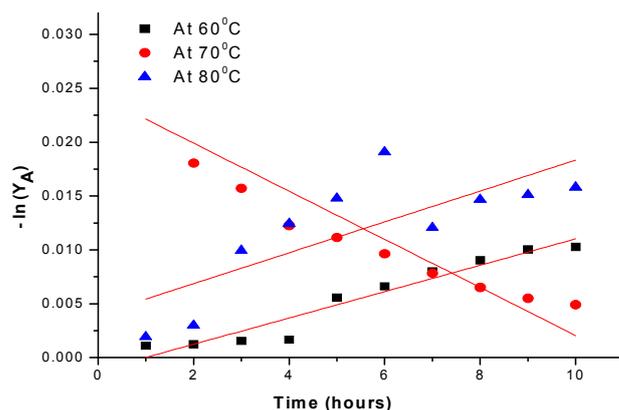


Fig. 12. Yield for the Methyl Archidate in Biodiesel Obtained from Rice Bran Oil

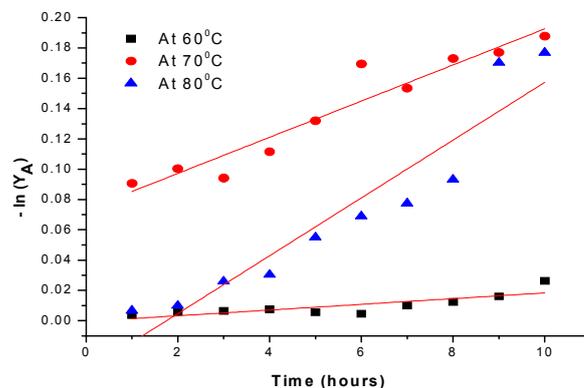


Fig. 13. Yield for the Methyl Tetra Deconate in Biodiesel Obtained from Rice Bran Oil

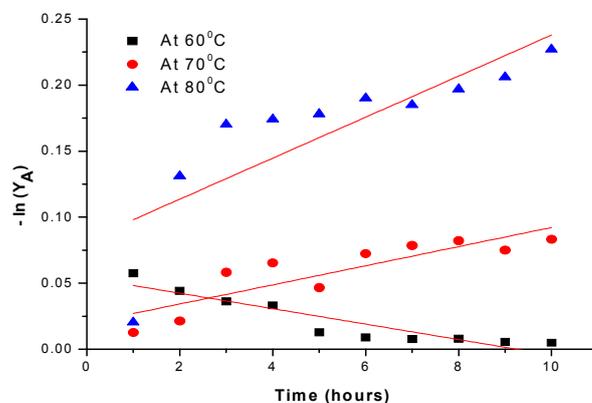


Fig. 14. Yield for the Methyl Penta Hexonate in Biodiesel Obtained from Rice Bran Oil

We have attempted to determine the rate constants from the experimental data using zero order, first order and second order kinetics. The first order kinetics has been seen to give the best results. In figure 6-14 for Rice bran oil (except data for methyl linoleate for which R^2 is 0.2) a first order is good representation because the value of R^2 is more than 0.8. Tables 1 also show the first order rate constants for various components and the overall rate constants cannot be obtained as some weighed average of rate constants of various components. In fact, the overall first order rate constant is higher as compared to the rate constants of individual components. This suggests that the overall mechanism as first

order is correct and there must be some additional mechanism of reaction leading to biodiesel formation.

Table 1. Reaction Kinetics of Rice bran oil for First order

Temp	Product name	$k \cdot 10^{-2} \text{h}^{-1}$	R ² Values
60°C	Overall	3.39	0.94
	Methyl Palmitate	0.86	0.98402
	Methyl stearate	0.8	0.8359
	Methyl oleate	0.8	0.87582
	Methyl linolenate	0.3	0.99481
	Methyl linoelate	0.33	0.2071
	Methyl eicosanolate	0.26	0.82868
	Methyl archidate	0.33	0.93134
	Methyl tetra deconate	0.12	0.64085
	Methylpentyl hexonate	0.5	0.83744
	70°C	Overall	6.28
Methyl Palmitate		1.3	0.91446
Methyl stearate		0.76	0.87521
Methyl oleate		0.76	0.82232
Methyl linolenate		0.6	0.9569
Methyl linoelate		0.6	0.47478
Methyl eicosanolate		0.4	0.93016
Methyl archidate		0.6	0.80654
Methyl tetra deconate		0.14	0.90959
Methylpentyl hexonate		0.7	0.7307
80°C		Overall	7.16
	Methyl Palmitate	1.35	0.46545
	Methyl stearate	1.9	0.76338
	Methyl oleate	1.0	0.93316
	Methyl linolenate	0.4	0.73812
	Methyl linoelate	0.42	0.46619
	Methyl eicosanolate	0.47	0.93818
	Methyl archidate	0.143	0.56576
	Methyl tetra deconate	0.15	0.88467
	Methylpentyl hexonate	0.14	0.62537

Conclusions

In this paper we have tested heterogeneous Mg-SO₄²⁻/ZrO₂ catalyst. Main focus of the work was made on zirconia supported catalyst which was tested for more than 1000h without loss of activity of purposed catalyst does not affect by the presence of free fatty acid (FFA) content in the Rice bran oil. Therefore this catalyst has novelty over other same class of catalyst for transesterification reaction. The GCMS analysis shows that there are ten major components in biodiesel even though they are present in different concentrations and their conversion with yields of individual components as a function of time. For temperatures less than 60°C, reaction was negligible or very small while above 80°C, the overall pressure in the reactor is very high (due to methanol. In view of this, the temperature variations studied were 60°C, 70°C and 80°C. Using gas chromatography, concentration of individual components was determined and the data fitting using first order plot was carried out. The goodness of fit was measured by R² values which are also reported in Table 1 most of the R² values are more than 0.8, this way confirming the goodness of the fit. The overall rate constant was considerably higher than individual rate constant of components for all oil indicating some side reactions also occurred which followed first order kinetics. It is likely that it may have diffused to the glycerol phase.

REFERENCES

Kawabata, T., T. Mizugaki, K. Ebitani and K. Kaneda, 2003. Highly efficient esterification of carboxylic acids with alcohols by montmorillonite-enwrapped titanium as a heterogeneous acid catalyst, *Tetrahedron Letters*, vol.44, pp. 9205–9208.

Zatta, L., J. E. F.da C. Gardolinski and F. Wypych, 2011. Raw halloysite as reusable heterogeneous catalyst for esterification of lauric acid, *Applied Clay Science*, vol.51, pp. 165–169.

Park, J. Y., D. K. Kim and J. S. Lee, 2010. Esterification of free fatty acids using water-tolerable Amberlyst as a heterogeneous catalyst, *Bioresource Technology*, vol. 101, pp. S62–S65.

Mello, V. M., G. P. A. G. Pousa, M. S. C. Pereira, I. M. Dias and P. A. Z. Suarez, 2011. Metal oxides as heterogeneous catalysts for esterification of fatty acids obtained from Soybean oil, *Fuel Processing Technology*, vol. 92, pp. 53–57.

Park, Y. M., J. Y. Lee, S. H. Chung, I. S. Park, S. Y. Lee, D. K. Kim, J. S. Lee and K.Y.Lee, 2010. Esterification of used vegetable oils using the heterogeneous WO₃/ZrO₂ catalyst for production of biodiesel, *Bioresource Technology*, vol. 101, pp. S59–S61.

Peters, T. A., N. E. Benes, A. Holmen and J. T. F. Keurentjes, 2006. Comparison of commercial solid acid catalysts for the esterification of acetic acid with butanol, *Applied Catalysis A: General*, vol. 297, pp. 182–188.

Sejidov, F. T., Y. Mansoori and N. Goodarzi, 2005. Esterification reaction using solid heterogeneous acid catalysts under solvent-less condition, *Journal of Molecular Catalysis A: Chemical*, vol. 240, pp. 186–190.

Marchetti, J. M., and A. F. Errazu, 2008. Comparison of different heterogeneous catalysts and different alcohols for the esterification reaction of oleic acid, *Fuel*, vol. 87, pp. 3477–3480.

Marchetti, J. M., V. U. Miguel and A. F. Errazu, 2008. Heterogeneous esterification of oil with high amount of free fatty acids, *Fuel*, vol. 86, pp. 906–910, 2008.

Sarkar, A., S. K. Ghosh and P. Pramanik, 2010. Investigation of the catalytic efficiency of a new mesoporous catalyst SnO₂/WO₃ towards oleic acid esterification, *Journal of Molecular Catalysis A: Chemical*, vol. 327, pp. 73–79, 2010.

Tsai, Y. T., H. Lin and M. J. Lee, 2011. Kinetics of heterogeneous esterification of glutaric acid with methanol over Amberlyst 35, *Journal of the Taiwan Institute of Chemical Engineers*, vol. 42, pp. 271–277.

Yadav, G. D. and M. B. Thathagar, 2011. Esterification of maleic acid with ethanol over cation-exchange resin catalysts, *Reactive & Functional Polymers*, vol. 52, pp. 99–111.

Miao, S. and B. H. Shanks, 2011. Mechanism of acetic acid esterification over sulfonic acid-functionalized mesoporous silica, *Journal of Catalysis*, vol. 279, pp. 136–143.

Yu, W., Y. Tang, L. Mo, P. Chen, H. Lou and X. Zheng, 2011. One-step hydrogenation-esterification of furfural and acetic acid over bifunctional Pd catalysts for bio-oil upgrading, *Bioresource Technology*, vol. 102, pp. 8241–8246.

Shengyang Hu, Yanping Guan, Yun Wang, Heyou Han, 2011. Nano-magnetic catalyst KF/CaO-Fe₃O₄ for biodiesel production, *Applied Energy*, vol. 88, pp. 2685–2690.

Rafiee, E., M. Joshaghani, F. Tork, A. Fakhri and S. Eavani, 2008. Esterification of mandelic acid catalyzed by heteropoly acid, *Journal of Molecular Catalysis A: Chemical*, vol. 283, pp. 1–4.

Kim, M., C. D. Maggio, S. Yan, H. Wanga, S. O. Salley and K. Y. Simon Ng, 2011. Performance of heterogeneous ZrO₂ supported metaloxide catalysts for brown grease

- esterification and sulfur removal, *Bioresource Technology*, vol.102, pp. 2380–2386.
- Niasari, M. S., T. Khosousi and S. Hydarzadeh, 2005. Highly selective esterification of tert-butanol by acetic acid anhydride over alumina-supported InCl_3 , GaCl_3 , FeCl_3 , ZnCl_2 , CuCl_2 , NiCl_2 , CoCl_2 and MnCl_2 catalysts, *Journal of Molecular Catalysis A: Chemical*, vol. 235, pp. 150–153.
- Rattanaphra, D., A. P. Harvey, A. Thanapimmetha and P. Srinophakun, 2011. Kinetic of myristic acid esterification with methanol in the presence of triglycerides over sulfated zirconia, *Renewable Energy*, vol. 36, pp. 2679-2686.
- Bhorodwaj, S. K., and D. K. Dutta, 2011. Activated clay supported heteropoly acid catalysts for esterification of acetic acid with butanol, *Applied Clay Science*, vol. 53, pp. 347–352.
- Shu-wen Gong , Jing Lu, Hong-hong Wang, Li-jun Liu, Qian Zhang , 2014. Biodiesel production via esterification of oleic acid catalyzed by picolinic acid modified 12-tungstophosphoric acid, *Applied Energy*, vol. 134, pp. 283–289.
- Borges M. E. and L. Díaz, 2012. Recent developments on heterogeneous catalysts for biodiesel production by oil esterification and transesterification reactions: A review, *Renewable and Sustainable Energy Reviews*, vol.16, pp. 2839–2849.
- Liu, W., P. Yin, X. Liu, W. Chen, H. Chen, C. Liu, R. Qu and Q. Xu, 2013. Microwave assisted esterification of free fatty acid over a heterogeneous catalyst for biodiesel production, *Energy Conversion and Management*, Vol. 76, pp. 1009–1014.
- Meng, Y. L., S. J. Tian, S. F. Li, B. Y. Wang, M. H. Zhang, 2013. Transesterification of rapeseed oil for biodiesel production in trickle-bed reactors packed with heterogeneous Ca/Al composite oxide-based alkaline catalyst, *Bioresource Technology*, vol. 136, pp. 730–734.
- Ramos, L. P., C. S. Cordeiro, M. A. F. C. Oliveira, F. Wypych and S. Nakagaki, 2014. Chapter 16 – Applications of Heterogeneous Catalysts in the Production of Biodiesel by Esterification and Transesterification, *Bioenergy Research: Advances and Applications*”, pp. 255–276.
- Xie W., and L. Zhao, 2014. Heterogeneous $\text{CaO-MoO}_3\text{-SBA-15}$ catalysts for biodiesel production from soybean oil, *Energy Conversion and Management*, vol. 79, pp. 34–42.
