



## Recent Advances in Heterogeneous Catalysts for Biodiesel Production

G. Baskar\*, R. Aiswarya, S. Soumiya, N. Mohanapriya, S. Roselin Nivetha

Department of Biotechnology, St. Joseph's College of Engineering, Chennai – 600 119. India.

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### ABSTRACT

Heterogeneous catalysts play a significant role in the production of biodiesel as they have many advantages over other catalysts. Heterogeneous catalysis is noncorrosive, requires mild environmental conditions with fewer disposal problems. The easy separation of product from the liquid is mainly achieved by the reusability as the catalyst settles at a faster rate. The use of this catalyst is widely used for biodiesel production due to higher activity, selectivity and longer lifetime of the catalyst. The heterogeneous catalyst reduces the overall production cost of biodiesel making it competitive with other petroleum-based diesel fuels. Recently, heterogeneous catalysts derived from nanomaterials have gained attention for biodiesel synthesis. Nanocatalyst characteristics, such as high catalytic activities and high specific surface area have helped overcome some limitations on heterogeneous catalysts for their applications in biodiesel production from biomass. This paper discusses the latest advances in research and development related with heterogeneous nanocatalysts. The use of nanocatalysts such as ferrous doped zinc oxide, copper doped zinc oxide and manganese doped zinc oxide for biodiesel production are discussed and compared.

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### 1. Introduction

The energy crisis is a major threat in recent times due to the depletion of major fossil fuels. Countries across the globe are still dependent on fossil fuels as their primary source of electricity and transportation fuel. Fossil fuels emit hazardous gases and are unsustainable due to their abate reserves. One of the possible ways to tackle this crisis is the identification of an alternative energy known as renewable energy. Biofuels such as biodiesel are renewable energy sources which are believed to be the forthcoming fuels [Yusuf et al., 2011]. Biofuels are liquid or gaseous fuels. They are attained from renewable resources. Biofuels are produced largely from biomass. They have an energy density, which is equivalent with conventional fossil based liquid fuels. Thermochemical, biological and chemical methods are the various production types of biofuels. Based on the availability of feedstock, the methods production methods mainly differs [Goyal et al., 2008]. Bioethanol, biomethanol, biohydrogen, biodiesel, biogas is the different type of biofuels that are available at present in various energy sectors.

Due to the resemblance between biodiesel and conventional diesel in terms of its chemical structure and energy content, biodiesel has been receiving the most attention among all other biofuels. Biodiesel can be produced from vegetable oil, waste cooking oil, and animal fats. Rapeseed, Soybean, Canola, Sunflower, Peanut, Palm oil, etc are some of the edible vegetable oil, which is used for the production of biodiesel. Non-edible vegetable oils such as *Jatropha curcas*, Sea mango, Pongamia etc. Currently, feedstocks that do not compete with food crops are on constant demand

[Gui et al., 2008]. Transesterification is typically used method to obtain biodiesel [Marchetti et al., 2007]. Transesterification reaction can progress either with catalytic or non-catalytic mechanisms. At supercritical conditions non catalytic reaction takes place. Catalytic reaction can be homogeneous, heterogeneous or enzymatic [Di et al., 2007]. Homogeneous and heterogeneous catalysts can be grouped as acidic, basic or enzymatic.

Most of the data showed favourable results for heterogeneous catalysts in biodiesel production than with homogenous catalysts. Heterogeneous catalysts are comparatively tolerant to high FFA and water content. Advancement of efficient and low cost heterogeneous catalysts for transesterification reaction can lower the overall production cost of biodiesel. This paper discusses the latest advances in research and development related with heterogeneous nanocatalysts used to produce biodiesel.

### 2. Biodiesel

Biodiesel is a backup fuel for diesel engines. Biodiesel is commonly produced by transesterification. It is a reaction between a triglyceride or animal fat with an alcohol. Biodiesel comprises of fatty acid alkyl esters (FAAE). Advantages of biodiesel are renewable nature, lower emissions of particulate matter and greenhouse gases [Ma and Hanna, 1999]. The other added advantage are its superior lubricity, high cetane number, high flash point, and high biodegradability [Ryan et al., 1984]. Biodiesel is a clear amber-yellow liquid. Its viscosity is similar to that of petroleum

\* Corresponding Author: [basg2004@gmail.com](mailto:basg2004@gmail.com)

diesel. They are biodegradable, non-flammable and non-toxic, and it notably reduces harmful emissions when burned as a fuel. Biodiesel can be pumped, stored and handled by using the same infrastructure and procedure that are employed for conventional diesel fuels [Al-Zuhair, 2007]. Transesterification is generally catalyzed by strong acid, strong base or enzymes resulting in biodiesel and glycerol [Encinaret al., 2005]. The most periodically used alcohols are acyl acceptors. Methanol is the widely used one and ethanol to a lesser extent. Propanol, butanol, isopropanol, tert-butanol etc are some of the other alcohols that can be used.

Homogenous catalysts provides fast reaction rate under milder reactions. One of the disadvantage of this process are the discharge of large quantities of waste-water due to washing of catalyst and glycerol [Kim et al., 2004]. Heterogeneous catalysts have an edge over homogeneous catalysts. Ease of separation of catalysts, recyclability, eco-friendly and environmentally benign etc are some of its advantages. Cleaner biodiesel can be produced using heterogeneous catalysts.

Due to environmental benefits biodiesel has gained wide attention recently. The main obstacle for commercialization of the biodiesel is the cost involved during the production of biodiesel. Feedstock is the major economic factor to be considered for the input costs of biodiesel production. Some of the other vital costs are labor, methanol and catalysts [Canakci et al., 2009]. Use of biodiesel is validated by the fact that the global emission of CO<sub>2</sub> is largely declined. Biodiesel involves an appreciable reduction of some of the toxic pollutants. This could be a key result for the reduction of urban pollution [Carraretto et al., 2004].

### 3. Catalysts involved in the biodiesel production

With some of the major developments and researches coming in the past years heterogeneous, enzymatic and other kinds of catalysts are growing up in the market. Heterogeneous catalyst outweighs the homogenous catalyst in terms of its cost, ease of separation and recyclability. They also provide production process as an ecofriendly method [Tanabe and HoElderich, 1999].

#### 3.1 Homogeneous catalysts

Homogeneous catalysts commonly used in the transesterification reaction are acidic and alkaline. The prevailing acidic homogenous catalysts used in the production of biodiesel are sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), hydrochloric acid (HCl). Alkaline catalysts incorporate sodium or potassium hydroxide and carbonates. High activity in transesterification were reported for alkaline catalysts. Some of the advantages of alkaline catalyst are associated with product supply, usability and easier handling. Disadvantages are the esterification process that lead to water formation inhibiting the overall process, unlikely of reusing the catalyst, corrosion of the catalysts, saponification and formation of emulsion at multiple stages. The loss of heat transfer and time increases the production costs [Raj and Sharath, 2011].

#### 3.2. Heterogeneous catalysts

Heterogeneous catalytic transesterification is a process where the catalysts remain in different phase to that of the reactants [Helwani et al., 2009]. Green technology have included heterogeneous catalysts due to the following characteristics: Recyclability of the catalysts, production of less amount of wastewater, Easier separation of biodiesel from glycerol [Sarma et al., 2008]. They convert the oil into biodiesel slowly but the obtained biodiesel is feasible in an economical way [West et al., 2008].

Large pore size to minimize diffusion problems is an ideal property of an solid (heterogeneous) catalyst [Brito et al., 2008]. Deactivation is mainly achieved due to high concentration of acid sites, high catalytic stability versus leaching and the probability to tune the hydrophobicity of the surface with the repulsion of highly polar compounds (Miao and Shanks, 2009). Advantages of heterogeneous catalysts are no waste is produced, a process set up is easy, investment and equipment based cost is lower, purification steps are not required, cost and environmental impact correlated with the expenditure in the distillation and refinery unit are erased. Disadvantages of heterogeneous catalysts are it requires higher temperature and pressure for the reaction to occur, thus it requires higher energy consumption and therefore utility and energy related costs are very high [Bobade et al., 2011].

### 4. Solid acid catalysts

Solid acid catalysts can be depicted based on the following criteria: Brønsted or Lewis acidity, strength, a number of these sites and morphology of the support. They are the most frequently used heterogeneous catalysts in the petrochemical industries. Solid acid catalysts are mainly used for

Table 1. Comparison of Homogeneous and Heterogeneous catalysts

Homogeneous Catalysts	Heterogeneous catalysts
Same phase as reaction medium. Insensitive to fatty acid and water content.	Usually distinct solid phase
Often difficult to separate	Readily separated
Expensive and difficult to recycle.	Readily regenerated and recycled
Often very high rates. Base catalysis highly favor kinetics	Rates not usually as fast as homogeneous
Not diffusion controlled	May be diffusion controlled
High selectivity	Lower selectivity
Short life and requires extensive purification step.	Long life and less purification step

organic reactions such as Friedel-Crafts. Some of its advantages are being in water and FFA tolerant in the transesterification reaction of oil. Solid acid catalysts can perform simultaneously esterification as well as transesterification [Clark, 2002].

Some of its drawbacks are it is a slow reaction and have adverse side reactions during transesterification reactions. For the transesterification of vegetable oil the solid acid catalysts are designed in such a way that the adsorption of oily hydrophobic species enters the catalyst surface. The deactivation of the catalysts is prevented by polar by-products like glycerol and water [Abebe et al., 2011].

#### 4.1. Zeolites as solid acid catalysts

Zeolites differ in pore structures, inner electric fields from crystal and surface properties contributing to various catalytic properties. It can accumulate on many types of cations such as Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup>. Acid sites and shape selectivity are the main characteristics of zeolites. Inexpensive nature, environmentally benign and generous surface area makes zeolite the most commonly used industrial catalysts. Zeolite activity depends upon the polarity, shape and size of the substrate and the reaction conditions. Higher activity is favored due to the higher reaction temperature [Bekkum and Kouwenhoven, 2007]. Ramos et al. used zeolites (mordenite, beta, and X) as a heterogeneous catalyst for the transesterification reaction of sunflower oil, which yielded methyl ester around 93.5–95.1 % (w/w) at a reaction temperature of 60°C.

#### 4.2. Functionalized oxides

Application of functionalized oxides catalysts helps simplify reaction systems by reducing the production costs and eliminating the environmental hazards, posed by various homogeneous catalyzed reactions. (Hermida et al., 2008). High surface area and stable functionalized solid acidic catalysts can be prepared from mixture of oxides like zirconia, silica, alumina, tungsten oxide and tin oxide. They are used for the transesterification and esterification of vegetable oils. Functionalized solid acid catalysts can also be synthesized from surface treatment of these oxides with acids like sulphuric and phosphoric acids [Hattori, 2004]. Sulphated zirconia was used for transesterification of soybean oil with methanol at a reaction temperature of 60°C and catalyst calcination temperature of 650°C, with 5 % (w/w) catalyst. It yielded FAME of 99.5 % (w/w). The recyclability was effective until the fourth cycle [Garcia et al., 2008]

#### 4.3. Other types of solid acid catalysts

Solid acid catalysts can be used effectively in the esterification of carboxylic acids. In order to obtain high conversion of triglycerides to biodiesel solid acid catalysts require higher reaction temperatures than base catalysts because of their low activity towards transesterification. Resins catalyze favorably both esterification and trans-esterification reactions under mild reaction conditions due to its higher concentrations of acid sites. Thermal stability and catalyst regeneration are the main problems associated with resin type of catalysts [Shruti et al., 2012].

## 5. Solid base catalysts

Solid base catalysts can be classified into five main types as single metal oxides, doped and mixed metal oxides, zeolites, supported alkali and alkaline earth metal oxides and hydrotalcite. Removal of water or CO<sub>2</sub> with high temperature is used to produce strong basic sites of solid base catalysts. The nature of these basic sites is based on their pretreatment temperature. Materials that act as a base toward reactants by abstraction of a proton (Brønsted base) or a donation of a lone pair of electrons (Lewis base) yield an intermediate anion known as a solid base. A higher activity compared to solid acid catalysts makes solid base catalysts to be widely used in the production of biodiesel [Lee et al., 2009].

### 5.1. Single metal oxides

Alkali, alkali earth and transition metal oxides are single metal oxides. Alkali earth metal oxides include MgO, CaO, SrO and BaO. The transesterification of vegetable oils catalysed by single metal oxides are studied extensively. By direct heating of their carbonate or hydroxide alkali earth metal oxides are synthesized. They are inexpensive, insoluble in alcohol and are non-toxic [McCaffrey, 1972].

#### 5.1.1. MgO as a heterogeneous catalyst

MgO comprises of weak basic strength and lower solubility in alcohol. To obtain higher basic MgO catalyst for the transesterification of vegetable oils calcination temperature, precursors and method of preparation are the main concern. Di Serio et al. reported the yield of biodiesel to be 92%(w/w) using 5%(w/w) of MgO catalyst with a methanol to oil ratio of 12:1 at a reaction time of 1hr.

#### 5.1.2. CaO as a heterogeneous catalyst

CaO exhibit high basic strength. They have lesser environmental impacts because of its lower solubility in methanol. CaO can be synthesized from cheap sources such as limestone and calcium hydroxide. Lam et al. reported the mechanism of CaO as heterogeneous base catalyst for the transesterification reaction. About 98%(w/w) of FAME yield were found to be achievable during the first cycle of reaction by using CaO catalyst for the transesterification process [Veljkovic, 2009].

#### 5.1.3. SrO as a heterogeneous catalyst

SrO is active and rapidly reacts with carbon dioxide. It is insoluble in methanol. Liu et al. reported that SrO had high basicity and used SrO for the transesterification of soybean oil. 90% FAME was yielded in 30 min at a temperature of 65°C with alcohol:oil of 12:1 and catalyst loading of 3%(w/w). Reusability of the catalyst was observed to be 10 times.

#### 5.1.4. BaO as a heterogeneous catalyst

BaO catalyst is toxic and easily dissolves in methanol. Patil and Deng studied transesterification of camelina sativa oil with methanol using BaO as catalysts. Maximum FAME yield was 83%(w/w) with 1%(w/w) of BaO at 100°C and at a reaction time of 3 hr.

### 5.2. Doped heterogeneous catalyst

Doping leads to the improvement of the basicity, high activity and stability. They are of paramount importance due to its environmental benefits, low cost and accessibility of these elements and compounds. Meher et al. examined doped alkali metals such as (Li, Na, K) on CaO for the transesterification reaction of karanja oil by varying 0.48-5.75% FFA content. It was reported that the yielded was 94.9%(w/w) using 2%(w/w) CaO with the lower FFA content at a reaction temperatures of 65 °C and reaction time of 8h. The yield dropped to 90.3 % (w/w) with the highest 5.75% FFA content. The studies revealed that alkali doping of CaO has enhanced the surface area, basic strength and pore size.

### 5.3. Supported alkali and alkali earth metal oxides

Alkali or alkali earth metals are the most prevailing source of super basicity. They are mostly opted as active catalysts on supported materials. These active metals can be enforced on a support such as metal or metal ion. Na, K, Li, Ba, Ca and Mg or their carbonates, hydroxides, halides and nitrates are the simple metallic forms. These can be supported on alumina and silica. The activity of the supported catalysts depends mainly on the basic strength than its specific surface area and pore volume during the process of transesterification. Teng et al. studied the activity of KF supported on gamma-Al<sub>2</sub>O<sub>3</sub> for transesterification reaction using different vegetable oils. A maximum FAME yield of 99%, was obtained on using soybean and sunflower oil with 2%(w/w) catalyst loading, 12:1 methanol to oil ratio at 65°C reaction temperature and at a reaction time of 3 hr.

Leaching of the active catalyst is the main obstacle associated with this catalyst for the decrease in the yield of biodiesel.

### 5.4. Hydrotalcite

They are a class comprising of anionic and basic clays. Polymer processing, pharmacy, good adsorbents and anion exchangers etc are important characteristics of hydrotalcites. Basicity of the mixed oxides is based on the type of synthesis method, activation temperature [Tichit et al., 1995]. The co-precipitation method is generally used for the synthesis of hydrotalcite. Tolerance to FFA and water are the advantages of hydrotalcite catalysts. Low surface area and porosity are some of its drawbacks. The active Mg Al-HT catalyst was synthesized by urea hydrolysis [Zeng et al., 2009]. It was calcined at 500°C for the transesterification reaction of rapeseed oil with methanol. The water content was kept below 2 % (w/w) and FFA below 3.0 mg KOH [g oil]<sup>-1</sup> with the yield of 94%(w/w).

### 5.5. Basic zeolites

NaX and NaY are the types of zeolites that are frequently used. For preparing basic zeolites cation exchange is the type of method that is generally used. The basic strength of the zeolites is based on the electro positivity of the cation exchange. Xie et al reported transesterification of soybean oil using KOH loaded on NaX. The 85 % (w/w) of FAME has been obtained. 3 % (w/w) of catalyst loading, 10:1 methanol to oil ratio, 66°C reaction temperature and reaction time of 8 hr was maintained. The yield was decreased to 48.7 % (w/w) due to high leaching of potassium from the catalyst when subjected to repeated cycles.

### 5.6. Mixed metal oxides and derivatives

The use of CaO–CeO<sub>2</sub> mixed oxides as solid base catalysts was reported for transesterification of *Pistacia chinensis* oil with methanol to produce biodiesel [Yu et al., 2010]. CaO–CeO<sub>2</sub> mixed-oxide catalysts were synthesized by an incipient wetness impregnation technique. Reaction parameters such as methanol to oil molar ratio, amount of catalyst and the reaction temperature were also studied. The catalyst Ce was found to be efficient with a calcination temperature at 973K and an molar ratio of 0.15. They were regenerated after five cycles with an yield of 91 % (w/w).

### 5.7. Transition metal oxides and derivatives

The transition metals and their oxides that are generally used are ZnO, TiO<sub>2</sub> as base heterogeneous catalysts [Yoo et al., 2010]. Yoo et al examined transesterification reaction to produce biodiesel from rapeseed oil using supercritical methanol with transition metal oxides such as ZnO, TiO<sub>2</sub> and ZrO<sub>2</sub>. Among them ZnO was reported the best catalyst for the transesterification of rapeseed oil due to its higher activity and less weight loss in supercritical conditions. Optimal reaction conditions was maintained with an molar ratio of methanol to oil 40:1, 1.0 % (w/w) of ZnO and a reaction time of 10 min. The supercritical process using ZnO was found to be efficient at economically viable conditions.

### 5.8. Waste materials based heterogeneous catalyst

Egg shell, mollusc shell, and bones etc are calcium sources that can be used as raw materials for catalyst production. This leads to the elimination of the wastes and simultaneously synthesis of catalysts at higher cost. For biodiesel production CaO based catalysts obtained from these waste materials are the ideal candidate. Soybean oil was used as a feedstock for biodiesel production. Parameters that were maintained for the production process includes the reaction temperature at 70°C, 6.9:1 molar ratio of alcohol to oil, 5 % (w/w) of catalyst load and reaction time of 5 hr. The catalyst could be reused for about 6 times. The FAME yield produced was reported as 97.73 % (w/w) [Du et al., 2004].

## 6. Nanocatalysts

Nanocatalysts have gained wide attention on transesterification reaction for the production of biodiesel due to the surface area of the nanomaterials. Immobilization of the lipase over a nanomaterial and the application of nanoparticles such as Al<sub>2</sub>O<sub>3</sub> metal oxides as heterogeneous catalyst is the recent development. High catalytic efficiency and ease in separation from products makes nanocatalysts a competitive candidate among all other heterogeneous catalysts [Zhang et al., 2010]. The magnetic Cs/Al/Fe<sub>3</sub>O<sub>4</sub> was used as a nanocatalyst for transesterification reaction of sunflower oil [Feyzi et al., 2013]. The results showed high catalytic activity for biodiesel production and the biodiesel yield was obtained around 94.8 % (w/w). Based on various studies on application of nanocatalyst for biodiesel



Table 1. Comparison of different heterogeneous catalysts for biodiesel production

Catalysts	Raw materials	Catalyst amount, % (w/w)	Molar ratio of methanol to oil	Reaction temperature	Reaction time	Rotation speed	Biodiesel yield, % (w/w)	Reference
Calcined oyster shell	Soyabean oil	25 wt.%	-	-	5 hr	-	70	[Nakatami et al., 2009]
CaO	Plant oil	0.1 g	3.9 g methanol 15 g rapeseed oil	333K	3 hr	-	90	[Kawashima et al., 2009]
Hydrotalcite	Rape oil	1.5	6:1	338K	4 hr	300 rpm	90.5	[Zeng et al., 2008]
SrO	Soyabean oil	-	-	Below 343K	Within 30 min	-	Over 95	[Liu et al., 2007]
KF/ZnO	Palm oil	5.52	11.43	333K	9.72 hr	-	89.23	[Hameed et al., 2009]
KF/CaO	Chinese tallow seed oil	4	12:1	65°C	2.5 hr	-	98%	[Wen et al., 2010]
Dolomite	Palm kernel oil	6 wt.%	30:1	60°C	3 hr		98.0%	[Ngamcharussri-vichai et al., 2010]
Mg-Al hydrotalcite	Soybean oil	5	13:1	230°C	1 hr		90%	[Silva et al., 2010]
Phosphazanium hydroxide/SiO <sub>2</sub>	Soybean oil	3.8 wt.%	60:1	75°C	12 hr		90%	[Kim et al., 2011]
K-ITQ-6	Waste oilseed fruits	5 wt.%	20:1	180°C	48 hr		87%	[Macario et al., 2010]
Quintinite-3T	Canola oil	10 wt.%	12:1	75°C	2 hr		97.28	[Kondamudi et al., 2011]
Sr/ZrO <sub>2</sub>	Waste cooking palm oil	2.7 wt	29:1	115.5°C	87 min		79.7%	[Omar., 2011]
Carbon-based solid acid	Cottonseed oil	0.2 wt.%	16.8:1	220°C	4.5 h		94.8	[Shu et al., 2010]

production, it is proved that the large porous catalytic surface increased the contact between alcohol and oil. This leads to a hike in nanocatalytic effectiveness. High specific surface area of nanomaterials in comparison with the bulk catalysts favors the contact between catalyst and substrates this in turn improve the yield of products [Mandana et al., 2014].

### 6.1. Ferrous doped zinc oxide nanocatalyst

Nanoparticles of ZnO comprises good optical, electrical and chemical properties [Xu et al., 2010]. Co<sup>2+</sup>, Ni<sup>2+</sup> and Fe<sup>3+</sup> etc are transition metal ions that can be used as dopant of ZnO to enhance the optical properties. Doping with various concentrations of Fe<sup>3+</sup> improves electron-hole pair separation by decreasing the band gap. It also decreases the size. Doped ZnO synthesized through co-precipitation method [Qiu et al., 2007] has many advantages over other production techniques such as ease of processing, control of composition, purity and homogeneity of the materials produced. Ferrous doped Zinc oxide catalysts produced by co-precipitation method demonstrated an efficient catalytic activity for the transesterification of castor oil with methanol. Parameters such as reaction time, catalyst loading, temperature, time and methanol to oil molar ratio gave a significant effect on the heterogeneous transesterification of Castor oil. Maximum biodiesel yield obtained from Castor oil was 90% at optimum conditions 50 min of reaction time, temperature of 55°C, 14 % (w/w) of Fe doped ZnO catalyst and methanol to oil molar ratio of 12:1 [Baskar and Soumiya, 2016]. Magnetic Composite of Zinc Oxide Nanocatalyst was reported for the production of from Pongamia oil [Baskar et al., 2016]

### 6.2. Copper doped zinc oxide nanocatalyst

AFM analysis confirmed the porous and non-uniform surface of the

CZO nanocatalyst. This lead to the aggregation of CZO nanoparticles in the form of multi layered nanostructures. The 97.18% (w/w) FAME yield was obtained. The optimized operating conditions are reaction time of 60 min, 55°C of temperature, 10 % (w/w) of CZO nanocatalyst and 1:10 (v:v) oil: methanol ratio. Stability and reusability of nanocatalyst are based on the presence of active sites. The nanocatalyst was reused and the biodiesel yield was stable till the sixth cycle. Therefore, CZO nanocatalyst has immense potential for the biodiesel production from low cost feedstocks like neem oil [Baskar and Aiswarya, 2015].

### 6.3. Manganese doped zinc oxide nanocatalyst

Mn doped Zinc Oxide heterogeneous catalyst showed effective catalytic activity for the conversion of Mahua oil into biodiesel through transesterification reaction with methanol. The good catalytic activity of zinc Oxide was observed as a result of doping effect. Manganese doping contributed to the rise in yield as it increases the surface area and basicity of Zinc Oxide. Various process variables that influences the yield were optimized such as calcination temperature (600°C), catalyst concentration (8 % (w/w)), oil to methanol ratio (7 v/v), Temperature (50°C), Time (50mins) and Mixing intensity at (250 rpm) [Baskar et al., 2017].

## Conclusions

The present study revealed the different types of heterogeneous catalysts and the resultant effect on biodiesel production. The presence of acid and basic sites on the surface of a catalyst paved way to produce biodiesel using heterogeneous catalysts as it avoids the problems caused by the use of homogeneous catalysts. Nanocatalysts successfully reduce reaction temperatures and energy consumptions since it requires only milder operating conditions. High specific surface area and high catalytic activity of nanocatalysts solves many of the problems of heterogeneous catalysts

like mass transfer resistance, time consumption, fast deactivation and inefficiency. Breakthrough is required for the design of catalysts with less complex or refined production methods, sustainable and environmentally benign precursors as well as reaction conditions. Thus, there is a need for further research in order to develop heterogeneous catalysts with better performance and applications.

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