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A review on catalytic biodiesel production

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Key words: Biodiesel, Catalyst, Transesterification, Vegetable oil, Animal fat.

Abstract

The industrialization of societies and as the result, the increase of demand for fuel in the world and speculations on the reduction of fossil fuels and on the other hand, the issue of world health emphasizes on the necessity of substituting renewable and clean energy, so biodiesel as the best substitute for diesel fuels is common. In general, three ways are used to produce biodiesel including pyrolysis, micro-emulsification and transesterification among which transesterification is known as the most usual and common way. The catalysts used in transesterification are divided into three groups of acidic, alkaline and enzymatic catalysts in which the acidic and alkaline catalysts in turn divide into two groups of heterogeneous and homogeneous. The Transesterification reaction using acidic catalysts involves more time for the reaction and high cost. The alkaline catalysts produce an appropriate amount of product in moderate operational conditions and show a better performance in comparison with the other catalysts. These catalysts have a limitation in use for raw material containing high free fatty acids. The way of using Lipase catalysts is the most viable method that can be applied, however it requires high costs. Given today's high total cost as the main obstacle for producing biodiesel, using animal fats and waste oils as raw material and using the heterogeneous catalysts and preferably renewable ones is suggested so as to reduce the total cost.

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Introduction

The invention of Internal combustion engines and the progresses made over the past years in the field of technology of making engines, has led to the great use of oil sources and quick evacuation of these sources. One type of such engines are the Compression-ignition engines or as they are commonly called the "diesel engine" which have a variety of uses in road and rail transportation, agriculture and other industries. The industrialization of societies and as the result, the increase of demand for fuel in the world and speculations on the reduction of fossil fuels from one side, and on the other hand, the issue of global hygiene and health, made the researchers concentrate their research on substituting renewable and clean energy for common fuels (Balat and Balat, 2010; Gerpen, 2005; Leung *et al*., 2010). Among these energies we can refer to solar energy and biofuels of which biodiesel is known as the most prevalent Biofuel (Balat and Balat, 2010; Basha, 2009; Leung *et al.,* 2010). Biodiesel due to its advantages such as better lubrication, complete combustion for having 10-12 percent oxygen weight and dissemination of fewer pollutants such as Carbon monoxide and Sulfur dioxides and also because of its biodegradability and its role in the reduction of global hygiene and health problems, has drawn the attention of researchers and nations (Dias *et al*., 2008; Ramus *et al*., 2004). In comparison to conventional fossil fuels, biodiesel lacks sulfur, aromatic hydrocarbons, metals and tiny particles of solid, hence biodiesel is called the clean or green fuel (Caynak *et al*., 2009) that can be used in a variety of cases either as a fuel directly or in combination with so-called diesel in cars (Guan *et al*., 2009), fuel for heating (Mushrush *et al*., 2001), aviation fuels and machines (Dunn, 2001), surfactants (Doll *et al*., 2008), lubricants (Willing, 1999) and also as a good solvent (Pereira and Mudge, 2004).

According to the definition American Society for Testing and Materials (ASTM), biodiesel is "mono-alkyl esters of long chain fatty acids derived from renewable fatty raw material such as vegetable oils or animals fats". The term "Bio" is the symbol of its renewability and biological origin and the term "diesel" is the symbol of its similarity to diesel fuel and its application in diesel engine (Guan *et al*., 2009; Graboaki and McComick, 1998; Demirbas, 2009).

Biodiesel production resources

Biodiesel can be produced from vegetable oils such as palm kernel oil, soybean oil, hazelnut oil, castor oil, corn oil, tobacco seed oil, Jatropha oil, mustard oil, sunflower oil and animal fats such as waste tallow, mutton tallow, fish oil, lard, chicken fat, as well as waste edible oils such as waste frying oils. Using animal fats and waste edible oils leads to the total cost reduction for producing biodiesel (Balat and Balat, 2010; Sbihi *et al*., 2014). Table 1 demonstrates some of the properties of produced biodiesel from various oil sources.

Table 1. Some of the properties for produced biodiesel from various oil sources (Sbihi *et al*., 2014; Ghobadian *et al*., 2005; Bhatti *et al*., 2008).

Methyl ester	Viscosity cSt	Specific gravity	Cloud point ˚C	Flash point ˚C	Cetane number	Heating value MJ/l	Ref
Camelus dromedaries fat	3.39	0.871	15.5	158	58.7	39.52	Sbihi *et al* (2014)
Peanut	4.9	0.883	5	176	54	33.6	Ghobadian *et al* (2005)
Soybean oil	4	0.880	-	-	45.7-56	32.7	
Palm oil	4.3-4.5	0.872-0.877	-	-	64.3-70	32.4	
Sunflower	4.6	0.860	1	183	49	33.5	
Canola oil	4.2	0.882	-	-	53	32.8	
Waste canola oil	9.48	0.895	-	192	63.9	36.7	
Waste corn oil	6.23	0.884	-	166	51	42.3	
Chicken fat	6.25	-	-5	-	61	-	Bhatti *et al* (2008)
Sheep fat	5.98	-	-4	-	59	-	
Waste frying oil	4.36	-	-3	-	53	-	

Vegetable oils have the highest proportion in biodiesel production. Vegetable oils contain more unsaturated fatty acids than saturated ones and hence, they usually possess appropriate cold flow properties. Table 2 demonstrates the amount of fatty acids in a number of vegetable oils (Marchetti JM, 2012). According to the statistics by Sciencedirect institute, in 2012 more than 5000 academic papers in the field of vegetable fuels have been published (Ebrahimi and Rahmani, 2012). The diversity and the extent of vegetable oils has created a potential for biodiesel production in different countries regarding various climate conditions. Table 3 demonstrates the amount of oil and main producers of some of vegetable oil seeds (Marchetti JM, 2012).

Table 2. Percentage of fatty acids in a number of vegetable oils (Marchetti JM, 2012).

Vegetable oil	Fatty acid composition (% by weight)								
	16:1	18:0	20:0	22:0	24:0	18:1	22:1	18:2	18:3
Corn	11.67	1.85	0.24	0.00	0.00	25.16	0.00	60.60	0.48
Cottonseed	28.33	0.89	0.00	0.00	0.00	13.27	0.00	57.51	0.00
Crambe	20.7	0.70	2.09	0.80	1.12	18.86	58.51	9.00	6.85
Peanut	11.38	2.39	1.32	2.52	1.23	48.28	0.00	31.95	0.93
Rapeseed	3.49	0.85	0.00	0.00	0.00	64.4	0.00	22.30	8.23
Soybean	11.75	3.15	0.00	0.00	0.00	23.26	0.00	55.53	6.31
Sunflower	6.08	3.26	0.00	0.00	0.00	16.93	0.00	73.73	0.00

Table 3. Main producers of some of vegetable oil seeds (Marchetti JM, 2012).

Seed	Amount of oil (%)	Productive areas
Canola	40-45	Canada, China, India, France, Austria, United Kingdom, Germany, Poland, Denmark, Chech, Republic.
Corn	3.1-5.7	USA, Mexico, Russia, Belgium, France, Italy, Germany, Spain, United Kingdom.
Cotton	18-20	China, Russia, USA, India, Pakistan, BBrazil, Egypt, Turkey.
Peanut	45-50	China, India, Nigeria, USA, Senegal, South Africa, Argentina.
Crocus	30-35	China, USA, Spain, Portugal.
Soybean	18-20	USA, Brazil, Argentina, China, India, Paraguay, Bolivia.
Sunflower	35-45	Russia, Argentina, Austria, France, Italia, Germany, Spain, United Kingdom.
Coconut	65-68	Filipinas, Indonesia, India, Mexico Sri Lan Ka, Thailand, Malaysia, Vietnam, Mozambique, New Guinea, Republic of Cote d´Ivoire.
Olive	15-35	Spain, Italy, Italia, Greece, Tunes, Turkey, Morocco, Portugal, Syria, Algeria, Yugoslavia, Egypt, Israel, Libya, Jordan, Lebanon, Argentina, Chile, Mexico, Peru, USA, Australia.
Palm	45-50	Malaysia, Indonesia, China, Filipinas, Pakistan, Mexico, Bangladesh, Colombia, Nigeria, Republic of Cote d´Ivoire
Palm Kernel	44-53	Malaysia, Indonesia, China, Filipinas, Pakistan, Mexico, Bangladesh, Colombia, Nigeria, Republic of Cote d´Ivoire

Due to the lack of the process of planting, conserving and harvesting in animal fats and also extraction of vegetable oils which leads to the total cost reduction for providing oil for biodiesel production, top photoobjectives and proper parameters, animal fats can be a more appropriate alternative than vegetable oils. On the other hand, Methyl ester from the transesterification of animal fats, because of having high unsaturated fatty acids possesses inappropriate cold flow properties. Statistics show that using merely animal fats does not have the potential of providing the world required fuel (Balat and Balat, 2010; Sbihi *et al.*, 2014; Jeong *et al.*, 2009). The important point which requires researchers' more attention is the amount of animal fats which is not that low compared with vegetable oils and can help to provide energy in the world (Canakci, 2007). On the other hand, producing biodiesel from waste edible oils is a promising alternative, since this type of oils can be provided in lower cost compared with fresh oils. Furthermore, using waste edible oils helps to protect the environment because these oils are discharged into the environment without any processing (Balat and Balat, 2010). From the other side, due to the exposure to high temperature, waste edible oils possess high levels of free fatty acids from which one-

stage biodiesel production causes a reduction in product level and two-stage biodiesel production applying such methods as pre-esterification causes an increase in production total cost (Nicheran, 2012).

Biodiesel production methods

So far, a lot of efforts have been made to produce biodiesel. There are three main and common methods to use vegetable oils and animal fats as diesel fuel which include: pyrolysis, micro-emulsification and transesterification.

Pyrolysis

In the method of pyrolysis, chemical changes are taken place through the use of heat in the presence of air or nitrogen. Thermal decomposition of triglycerides leads to the creation of several groups of material such as alkanes and alkenes, alkadyns, the aromatics and carboxylic acid. The resulting fuel from this method has low viscosity and high cetane number compared with pure vegetable oils. In this method appropriate amounts of sulfur, water, deposits and corrosion rate of copper and inappropriate amounts of ash, carbon residue and cloudy spot are produced (Ghobadian *et al*., 2005; Ranganathan *et al*., 2008; Srivastava and Prasad, 2000).

The process of chemical preparation in this method is similar to the process of preparing diesel fuel derived from petroleum and with the egression of oxygen during the thermal process, the eco-friendly advantages of loving the environment for using Oxygenated oils vanish (Ghobadian *et al*., 2005; Ranganathan *et al*., 2008).

Micro-emulsification

Applying micro-emulsification by using the solvents methanol, ethanol, and butanol to improve the physical properties such as high viscosity of vegetable oils and blended material is immiscible. Microemulsions are isotropic, transparent and thermodynamically stable and consist of oil particles, water and surfactant and often small amounts of amphiphilic molecules which are called *co-surfactant* (Srivastava and Prasad, 2000; Fukuda *et al*., 2001). In this method low viscosity is obtained for the fuel, but from the other side, this fuel has a low cetane number and little energy and the combustion would be done incompletely and much carbon deposits will come out (Boro *et al*., 2012).

Transesterification

Transesterification is the most common method for producing biodiesel. Transesterification is done through vegetable oil or animal fat reaction with alcohol in presence of appropriate catalyst (Alkali, acid, enzyme) to produce alkyl ester and glycerin as a valuable by-product. In this method, the resulting biodiesel has high cetane number, low emission of pollutants, and high combustion efficiency and besides, this method leads to conserve oxygen atoms in biodiesel molecule. Fig. 1 shows the above-mentioned reaction (Ghanei *et al*., 2011):

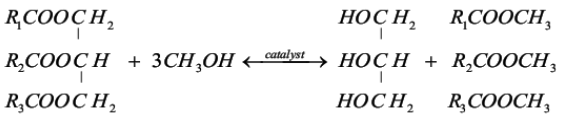

Fig. 1. Transesterification reaction scheme.

Alcohols in transesterification reaction

Appropriate alcohols in transesterification method for producing biodiesel are methanol, ethanol, propanol and butanol among (Vicente *et al*., 2004) which methanol is used more than ethanol and other alcohols due to its low price and availability. For this reason biodiesel is also called fatty acid methyl esters or "FAME" (Guan *et al*., 2009; Demirbas, 2009). Although alcohol's stoichiometric ratio to oil is 3:1, this ratio is more considered to facilitate the dissolution and the collision of alcohol and oil molecules. Furthermore, extra amounts of alcohol cause the reaction to transfer toward products and increase the conversion rate of methyl ester which is extremely depended on the kind of used catalyst (Guan *et al*., 2009; Ghanei *et al*., 2011). According to the investigation made by some researchers it has been defined that the kind of alcohol used in the reaction affects the reaction conversion rate and

biodiesel physical properties. Canakei *et al* (2007) examined the effect of the kind of alcohol on the transesterification reaction, the result of which has been presented in Table 4. The conducted surveys show that using ethanol instead of methanol causes the resulted fuel to have high biodegradation level. It has also been shown that using alcohols with longer chain produces fuels with better cold flow properties (McNeff *et al*., 2008).

Catalysts in transesterification reaction

In general the catalysts that can be used for producing biodiesel are divided into three groups: alkaline, acidic and enzymatic. Compared with other catalysts alkaline catalysts show a better performance. Alkaline and acidic catalysts are also classified into two groups: Heterogeneous and homogeneous catalysts (Leung *et al*., 2010; McNeff *et al*., 2008). Fig. 2 demonstrates catalyst classification and table 5 presents a comparison of catalyst types which can be used for producing biodiesel (Leung *et al*., 2010; Graboaki and McComick, 1998; Li *et al*., 2009; Chouhan and Sarma, 2011).

Table 4. Effect of the type of alcohol on the conversion rate and biodiesel density (Canakci, 2007).

kind of Alcohol	Boiling Point (K)	Reaction Temperature (K)	Conversion (%)	Specific gravity
Methanol	338	333	87.8	0.8876
Ethanol	351.5	348	95.8	0.8814
2-Propanol	355.4	348	92.9	0.8786
1-Butanol	390	383	92.1	0.8782

Table 5. Comparison of various types of catalysts in the transesterification of oils ((Leung *et al*., 2010; Graboaki and McComick, 1998; Li *et al*., 2009).

Catalyst	example	Advantages	Disadvantages
Homogeneous alkaline	NaOH KOH	High catalytic activity, Low cost, Favorable kinetics and mild operating conditions	Need to feed without FFA and water, Saponify, Forming emulsions, High effluent for washing, Catalyst Loss
Heterogeneous alkaline	CaO, CaTiO3,CaZrO3, CaO-CeO2, CaMnO3, Ca2Fe2O5, KOH/Al2O3, KOH/NaY, KI/Al2O3, ETS-10 Zeolite, K2CO3/Alumina-silica	Non-corrosive, Environmentally friendly, Recyclable, Easy segregation, Less excretion, Appropriate selectivity and long life	Need to feed without FFA and water, Need to a high ratio of methanol to oil, High pressure and temperature, Penetration limits and high prices
Homogeneous acid	Strong sulfuric acid	Simultaneous advancing of the esterification process along with transesterification and preventing the formation of soap	Device Corrosion, High effluent, Catalyst loss, High temperature, Long time and low catalytic activity
Heterogeneous acid	carbon based solid acid, carbohydrate drived catalyst Vanadyl phosphate, Niobic acid, Sulphated zirconia, Amberlyst-15, Nafion-Nr50	Simultaneous advancing of the esterification process along with transesterification, Environmentally friendly and recyclables	Low density of acid sites, Low porosity, Penetration limits and high prices
Enzymes	Candida Antarctica fraction B lipase, Rhizomucor mieher lipase	Preventing the formation of soap, Non-polluting, Easy purification of the product	Costly and transmutation

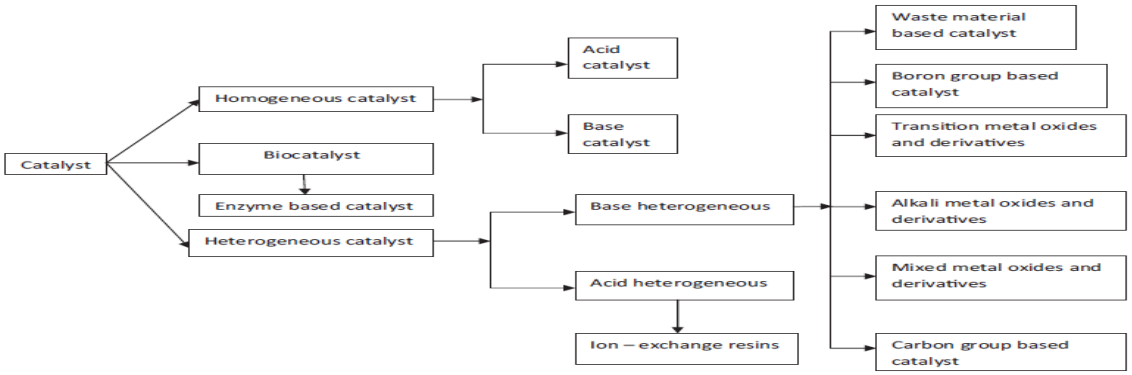

Fig. 2. Catalyst classification (Chouhan and Sarma, 2011).

Acidic catalysts

Organic and mineral acids as catalysts are active in transesterification, such as sulfuric acid, hydrochloric acid (Jeong *et al.*, 2009), phosphoric acid of mineral types and toluene and benzene sulfonic acid derivatives as organic acids (Balat and Balat, 2010), acetate, and calcium stearate, barium, magnesium, cadmium, titanium, lead and nickel, which acetates generally showed less activity than stearate (Serio *et al.*, 2005), Even though, at times the process of transesterification of acids is up to 4000 times slower than Alkaline types (Georgogianni *et al.*, 2009; Wen *et al.*, 2010), when the feed possesses water impurities and a great amount of free fatty acids, this kind of catalysts is preferable (Soriano *et al.*, 2009). This kind of catalyst produces a lot of products but its reaction is done quite slowly.

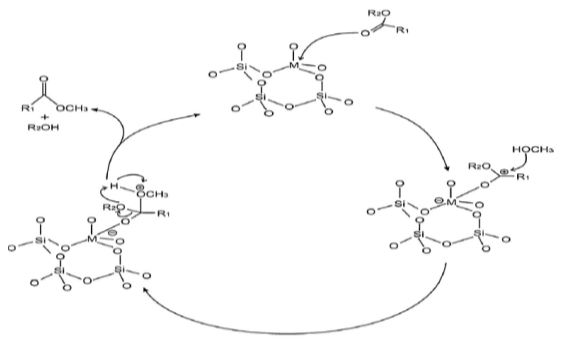

Fig. 3. The transesterification mechanism in the presence of acid catalyst (Chouhan and Sarma, 2011).

On the basis of Helwani *et al.* (2009) report this kind of reactions generally require temperatures higher than 100°C and between 3 to 50 hours time. Besides, to reach a higher efficiency, greater amount of methanol close to the ratio of 30:1 is needed. Of the most popular catalysts we can refer to sulfuric acid, hydrochloric acid and phosphoric acid (Canakci, 2007). Chemical mechanism of acidic catalyst is demonstrated in Fig. 3 (Chouhan and Sarma, 2011).

Alkaline catalysts

Types of alkaline catalysts such as Alkoxides, hydroxides, carbonates and oxides of alkali and alkaline earth metals are highly active in transesterification reaction to produce biodiesel so that in lower amounts of catalyst and alcohol the reaction can take place in low temperature (Balat and Balat, 2010; Shu *et al.*, 2007).

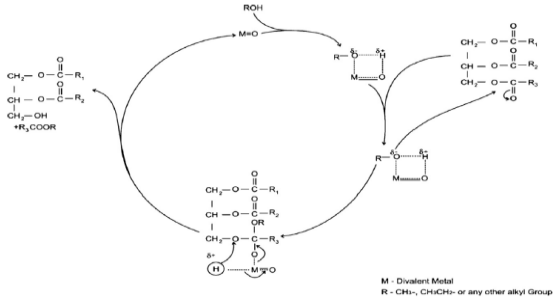

Fig. 4. The transesterification mechanism in the presence of heterogeneous base catalyst (Chouhan and Sarma, 2011).

The used catalyst has an important role in defining the time of reaction. The reason for high tendency to use base reactions is more impact and less corrosion compared with acid reactions.Of the most popular and applicable base catalysts we can refer to sodium

and potassium hydroxide and methoxide (Canakci, 2007). The limitation for the use of these catalysts is related to the purity level of food and raw materials so they should be without water because water generates soap and using the raw material, emulsion is formed and this makes purification difficult and costly (Chouhan and Sarma, 2011; Semwal *et al.*, 2011). Transesterification mechanism in the presence of heterogeneous base catalyst has been demonstrated in Fig. 4. (Chouhan and Sarma, 2011).

Enzymatic catalysts

Although acid and base chemical Transesterification is successful in producing biodiesel, the energy consumption is high and acid or base should be separated from the product and this causes hazardous effluents. Lipases are enzymes that can be applied as catalyst in the transesterification reaction. This process is quite optional and neat however it requires a long time (Balat, 2009). In general the advantages and disadvantages for using lipases are as follows:

Advantages for using lipases (Demirbas, 2007):

1. The remnant of these materials is renewable and decomposes in the life cycle.
2. They are approximately sustainable to changes in temperature.
3. Non-moving property of lipase causes it not to be dissolved in reactive substances and as a result the whole lipase acts as an enzyme.
4. Applying catalysts in reaction, the product separation would be facilitated.

Disadvantages for using lipases (Balat, 2009; Demirbas, 2007):

1. Prolongation of reaction time
2. High cost
3. Enzyme does not support reactive substances steadily.

Comparison of heterogeneous and homogeneous catalysts

Using multistage homogeneous processes causes the process to extend and is followed by production high cost including effluent costs, product purification and catalyst neutralization (Leung *et al.*, 2010; Guan *et al.*, 2009). By substituting solid catalysts for homogeneous catalysts, various processes of separation, corrosion and hazardous effluents would be omitted (Leung *et al.*, 2010; Borges and Dias, 2012). In processes in which homogeneous catalysts are used, the catalyst should be ultimately neutralized and cannot be reused (Borges and Dias, 2012) whereas heterogeneous catalysts are applicable in the process easily, they can be retrieved and reused. Using solid catalysts in fixed bed reactors are also quite easier in constant processes (Guan *et al.*, 2009; Graboaki and McComick, 1998; Li *et al.*, 2009). Among the most important features of heterogeneous catalysts, we can refer to the lack of soap formation which causes the water used for washing to reduce and so there would not be a probability for making an emulsion while washing (Serio *et al.*, 2005). Besides, the resulted products including biodiesel and glycerin are clean and they don't need purification any more (Georgogianni *et al.*, 2009; Li *et al.,* 2014). Compared with homogeneous catalysts, heterogeneous catalysts show less sensitivity to the presence of FFA (Wen *et al.*, 2010). There are also some disadvantages for heterogeneous catalysts including low activity, high reaction temperature, needing auxiliary solvent, long reaction time and moisture sensitivity (Soriano *et al.*, 2009). Sakai *et al.* (2009) made a comparison between 4 homogeneous and heterogeneous catalyst processes, respectively on the basis of KOH and CaO. In this research it was defined that heterogeneous processes were relatively cheaper and their products had the potential of competition in the current market. One of the most important features of solid catalysts is lack of dissolution in reaction mixture in the condition of reaction process (Serio *et al.*, 2005). Zabeti *et al.* (2009) have mentioned the most effective parameters in heterogeneous catalyst activity as specific area, cavity volume and the density of active sites on the surface. The use of a support for the reduction of mass transfer resistance and the catalyst increased longevity and efficiency has also been considered

quite effective (Graboaki and McComick, 1998). Table 6 shows the reviewed article about transesterification through heterogeneous catalysts over the past years.

Table 6. Reviewed articles on transesterification by heterogeneous catalysts.

No	Research subject	Research period (year)	Comments	Ref
1	Solid heterogeneous catalysts for transesterification of triglycerides with methanol: a review	1984-2007	This review focuses on the use of different methods for producing biodiesel and catalysts for transesterification reaction	Helwani *et al* (2009)
2	Activity of solid catalysts for biodiesel production: a review	1993-2007	Description of Catalyst activities	Zabeti *et al* (2009)
3	Recent inventions in biodiesel production and processing – a review	1974-2007	This review focuses on recent technologies in the field of biodiesel	Sarma *et al* (2008)
4	Biodiesel production by heterogeneous catalysts and Supercritical technologies	1987-2010	This review focuses on different new technologies of solid catalysts and non-catalytic supercritical process	Lee and Saka (2010)
5	Parametric sensitivity in transesterification of waste cooking oil for biodiesel production-a review	2002-2006	This review focuses on advances in esterification and transesterification reaction to facilitate biodiesel production	Banerjee *et al* (2009)
6	Latest developments on application of heterogeneous basic catalysts for an efficient and eco friendly synthesis of biodiesel: a review	2005-2010	This review focuses on alkaline heterogeneous catalysts such as oxides of magnesium, calcium, alumina and zeolites	Sharma *et al* (2011)
7	Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: a review	1998-2007	This review focuses on the advantages and limitations of using heterogeneous, homogeneous and enzymatic catalysts in transesterification reaction	Lam *et al* (2010)
8	Technologies for biodiesel production from used cooking Oil-a review	2002-2009	This review focuses on the production and description of biodiesel fuel and its comparison with diesel fuel	Math *et al* (2010)
9	Biodiesel production using heterogeneous catalysts	2003-2009	This review focuses on the production of biodiesel using appropriate heterogeneous catalysts to produce biodiesel. This research will help to select a catalyst and suitable operating conditions.	Semwal *et al* (2011)
10	Upstream and downstream strategies to economize biodiesel production	1999-2009	This review focuses on the various methods for biodiesel production and their advantages and disadvantages	Hasheminejad *et al* (2011)
11	Modern heterogeneous catalysts for biodiesel production: A comprehensive review	2001-2010	This review focuses on the alkali, acid, alkali – acid catalysts and biocatalysts to produce bio-diesel.	Chouhan and Sarma (2011)
12	Recent developments on heterogeneous catalysts for biodiesel production by oil esterification and Transesterification reactions: A review	2001-2011	This review focuses on the studies of the effect of recent catalysts used to produce biodiesel at low temperatures	Borges and Dias (2012)

Summary

Due to their diversity and extent, vegetable oils have a high potential in biodiesel production which of course, because of having the stages of Planting, conserving and harvesting and also the stage of oil extraction causes the biodiesel total price to increase. Therefore, using animal fats and waste oils can help the total cost for producing biodiesel to decrease. Among the used alcohols for transesterification reaction, methanol draws more attention for its low cost and availability. In general the used catalysts in the transesterification reaction of triglyceridesare are divided into three groups: acidic, alkaline and enzymatic. Using alkaline catalysts, the appropriate product with favorable conversion rate is produced which has a more suitable performance compared with other catalysts. The limitation for the use of alkaline catalysts is the existence of water in raw material, high free fatty acids in the oil. By using acidic catalysts, a good conversion rate is acquired but its requisite is spending a long time and as the result, increased cost for reaction. Using these catalysts is preferable when the feed has an amount of high free fatty acids. Over the past years, favorable results have been presented about the application of lipase in transesterification reaction but similarly, high cost and the reaction long time were among the obstacles to prevent us from using these catalysts in biodiesel industrial production. Given that today high total cost is the main obstacle for producing biodiesel, using animal fats and waste oils as the raw material and using renewable heterogeneous catalysts like CaO from eggshell, oyster, crab shell, etc is suggested to reduce the total cost for producing biodiesel.

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