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Review Article
Comprehensive Study on Biodiesel Produced from Waste Animal Fats-A Review

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Abstract
Biodiesel is a long chain fatty acid alkyl ester molecule with robust characteristics suitable for both environment and as alternate energy resources. This paper aimed in summarizing the detailed literature study on biodiesel produced from waste animal fats discarded from leather tanneries and animal slaughter houses. This study concentrated on the extraction techniques, refining process, biodiesel production process along with its advantages and effect on engine. The fats had been proven to a viable feedstock when compared to vegetable oil and waste cooking oil in terms of productivity and economy. Various technical challenges involved in biodiesel production are food vs. fuel conflict over feedstock, auxiliary energy requirement for fat extraction and biodiesel production, Free Fatty Acid content, optimizing the reaction. Effects of biodiesel on engine application had also been discussed and will be providing wider scope of research for overcoming these short comes. This literature study affirmed that biodiesel produced from waste animal fat has a very good impact in reducing environmental pollution and moving a step ahead towards an effective sustainable development.

Key words: Biodiesel, waste animal fats, tanneries, animal slaughter houses, food vs., fuel conflict

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The resurgence of biodiesel rose shortly after the controversy regarding the depletion in fossil fuel reserve broke in early 2000's. Based on the statistical report issued by Oil and Gas Journal (O and GJ), the worldwide reserve of crude oil and natural gas fell from 1.3 trillion barrels to 85 million oil barrels and 6,000 trillion cubic feet of natural gas to 250 billion cubic feet respectively, with a reserve rate of only forty years[1]. On commercialization, biodiesel was used as the successful replacement for petro diesel because of its high environmental sustain ability and better performance and emission characteristics during combustion[2]. In recent times, it has been even used as non-volatile solvent for degrading crude oil spilled during ship wreckages[3,4]. Biodiesel is a fatty acid alkyl ester which is produced by transesterifying triglycerides present in oil or fat with organic solvent such as methanol[5], ethanol[6], butanol and even pentanol in presence of homogeneous or heterogeneous catalyst under optimum temperature[7] and time[8]. The sources for triglycerides are unsaturated vegetable oils, saturated animal fats, discarded or reprocessed greases and edible oil processing wastes having different compositions of fatty acids, either bonded with other glyceride molecules as triglycerides or as independent Free Fatty Acids (FFA)[9]. This bio-degradable fuel is non-toxic with zero effect on environment[10] and has very low level of CO, SO, hydrocarbon emissions. They have unique characteristics like high oxygen content, high cetane number with no aromatics and zero sulphur content[11,12]. These properties make this biofuel sustainable and renewable, thus enabling it to be used for combustion and energy based applications.

Numerous researches have been cried out on biodiesel production from plant seed oil whereas limited researches have been performed on transesterification of animal fat for biodiesel production. Initial work on animal fat was based on transesterifying waste fleshing oil and evaluating its performance on a diesel engine[13]. As the viability of the biodiesel turned out to be feasible, the physiochemical properties for a mutton waste fat biodiesel were analyzed along with its emission and combustion characteristics[14]. The study moved ahead towards understanding the composition of biodiesel by transesterifying duck tallow with potassium hydroxide as catalyst, which explained that the end result obtained was oleate, a transesterified product of oleic acid[15]. In addition to meat processing wastes, fleshing wastes from leather industries have proved to be an alternative source of fat for biodiesel production, which can be blended to ordinary diesel for combustion based application[16,17]. These wastes are discarded into environment because of its zero usability.

IDENTIFICATION OF FEEDSTOCK

Based on the economic analysis on biodiesel, nearly 85% of overall production cost was associated with the feedstock usage and handling[9,18]. Presently, oils from the corn, soybean, safflower, cottonseed, peanut, sunflower and rapeseed along with another 350 crops have been identified as potential feedstock with high fat content for producing biodiesel which is suitable for running in diesel engines[19-23]. But these feed stocks have turned out to be less cost effective, more time consuming (considering life cycle analysis) and serious concern related to "Food vs. fuel" conflict. However, to reduce the price of biodiesel while competing with the diesel fuel and surviving in market, diverse kind of low cost feedstock's likes animal fats, recycled greases, used vegetable oil, waste cooking oil, by products of refining vegetable oil and soap stocks have been identified for low cost biodiesel production[12,24-28]. Waste animal fats obtained from tanneries, slaughter houses and meat processing units are considered as highly potential feedstock for biodiesel production because of its chemical inertness, zero corrosivity, better calorific value and renewable resources. Among these sources, leather tanneries produces 55% of solid wastes during trimming, prefleshing, fleshing and shaving operations, which majorly consist of subcutaneous fat wastes[29]. Using these wastes not only reduces the solid waste disposal, but also reduces the overall production cost of biodiesel[30]. Figure 1 explains the yearly production of various animal fat and grease in United States of America over a time span of 6 years. The graph also shows the constant production rate of greases and inedible tallow, allowing it to be used as feedstock for biodiesel production.

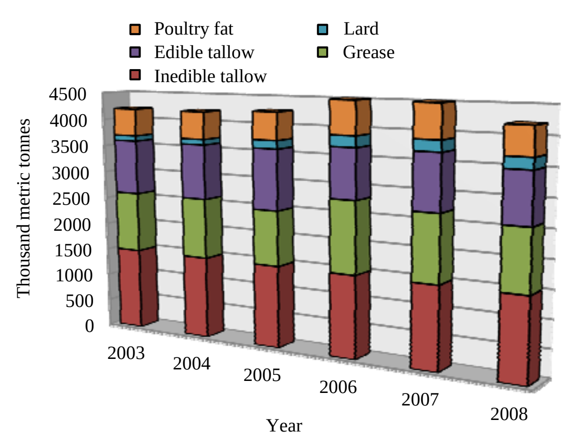

Fig. 1: Graphical representation of Animal fat and grease production rate in United States of America[31]

Table 1: Chemical composition (% by weight) of fatty acids in various animal fats

	Chemical composition of fatty acids (% weight)							
Products	Myristic acid C14:0	Palmitic acid C16:0	Palmitoleic acid C16:1	Stearic acid C18:0	Oleic acid C18:1	Linoleic acid C18:1	Linolenic acid C18:3	Saturation levels
Beef tallow	3-6	24-32	-	20-25	37-43	2-3	-	47-63
Pork lard	1-2	28-30	-	12-18	40-50	7-13	-	41-50
Yellow grease	2.43	23.24	3.79	12.96	44.32	6.97	0.67	38.63
Brown grease	1.66	22.83	3.13	12.54	42.36	12.09	0.82	37.03

Table 2: Fat distribution in pork lard and beef tallow

	Fat distribution for pork lard and beef tallow						
	Beef			Pork			
Fatty acids	Intramuscular fat	Subcutaneous fat	Kidney fat	Back fat	Belly fat	Intramuscular fat	Leaf fat
Palmitic acid (16:0)	24.7	24.6	25.0	24.4	25.5	26.0	28.5
Stearic acid (18:0)	18.3	11.1	29.2	16.6	16.8	15.4	20.1
Vaccenic acid (18:1)	42.4	46.6	33.5	44.1	41.3	43.0	37.2
Linoleic acid (18:2)	1.9	1.7	1.5	8.9	8.2	7.3	7.3

CHEMISTRY OF ANIMAL FAT

The fat primarily consists of (i) Triglycerides, (ii) Phospholipids and (iii) Sterols. The triglyceride molecule compromises of three fatty acids molecules connected with a common glyceride spine having substantial amount of oxygen infused in its structure[32] and these fatty acids reacts with alcohol during transesterification reaction to produce Fatty Acid Alkyl Ester (biodiesel). The difference between fat and oil is based upon the saturation and its degree in the carbon chain. Oil exists in liquid phase because of unsaturated fatty acids (monounsaturated, polyunsaturated) whereas animal fats like suet, tallow and lard exist in solid state because of saturated fatty acids. The variation in fatty acids is based upon the number of carbon in the chain, degree and number of saturation in it[33]. The phospholipids can be removed by degumming the fats using orthophosphoric acid (in case of acid degumming) or with water (in case of water degumming). Vegetable oils have high unsaturated fatty acid (mainly oleic and linoleic acid) content whereas animal fat has good amount of fatty acids with saturation (Palmitic and stearic). Most commonly used waste animal fats for biodiesel production are pork lard[34], lamb meat, beef tallow, chicken fat and animal fat mix[35]. The recycled greases consists of monoglycerides (MG), diglycerides (DG), triglycerides (TG) and varying amount of FFA (8-40%) depending upon its source. The saturated fats are easily hydrolyzed on prolong exposure to wet environment thereby increasing its FFA% content, which in turn reduces the quality of the fat for reaction[36]. Table 1 and 2 represents the chemical composition (% by weight) of fatty acids present in various animal fats and overview of the fat distribution for pork lard and beef tallow, respectively[37-39].

EXTRACTION OF ANIMAL FAT

Fat are usually found in form of fat-protein matrix at adipose tissues and fat-muscular matrix in muscular fats (intermuscular and intramuscular). Fats are commonly extracted from these wastes by following extraction methods: Thermal, chemical and enzymatic. Thermal extraction methods deals with rendering of fat using heat which melts the fat into liquid and forces it out of the matrix. Most commonly known hot rendering techniques are auto clave extraction, where the fat are separated using the high temperature and pressure inside the reactor vessel[40]. This extraction method cooks the wastes inside the oven operating at a temperature of 120°C with pressure of 15 bar under vacuum condition which causes the fats to get separated from non-fatty residues. The extraction rate can be further improvised by employing microwave energy which produces more heat energy upon interaction with water molecules present in the wastes[41]. Fat extraction with better performance can be achieved using chemical method, where organic solvents like hexane are used for dissolving the fats leaving behind the residues. This technique is employed in Soxhlet's extraction method, hexane vapors squeezes out the fat content from the wastes by means of Soxhlet's apparatus. the principle behind this technique is hydrogen bonding and van der Waals bonds along with electrostatic interaction breaks whereas the covalent bond remain untouched on interaction with solvent[42]. Enzymatic hydrolysis provides the highest extraction rate through the means biochemical reactions, which has gained interest in biofuel industries.

Table 3: Pre-processing techniques for waste animal fats

Treatments	Process description	References
Filtration	Removes residual solids, inorganic materials and carbonaceous materials	Pahn and Pahn[43] and
	Procedure: Vacuum suction operated above the melting temperature of fat	El Sherbiny *et al.*[44]
Centrifugation	Removes unfiltered solid particles	
	Procedure: Centrifuged at 4000 RPM for 25 min	
Preheat treatment	Eliminates the water and moisture content	
	Procedure: Heating the fat over 100°C	Sudhir *et al.*[45]
Deacidification	Removes free oily fats	Pahn and Pahn[43],
(Neutralization)	Procedure:	Sudhir *et al.*[45]
	Neutralize with alkali solution	and Cvengros and
	Neutralization by caustic soda	Cvengrosova[46]
	Glycerin esterification	
	Solvent (ethanol) extraction	
	Distillation method	
	Ion exchange method	
Steam injection	Increases calorific value, decreases kinematic viscosity, humidity, FFA content	Supple *et al.*[47]
	Procedure: Steam injection and sedimentation method	

PREPROCESSING OF FATS

The extracted fat must be preprocessed before being subjected for further reaction in order to achieve maximum biodiesel yield from it. It includes separation of macro non-fatty residues and water content present in the fats, neutralizing the pH and liquefying it for easy handling. Various processes involved in the preprocessing of fats are tabulated in Table 3.

FREE FATTY ACID CONCENTRATION

Free fatty acids are the fatty acids which get separated from glycerol spine during hydrolysis upon continuous exposure to moisture environment for prolonged time. The fat reacts with water to form free fatty acids and glycerol. Generally, fatty acids attached with glycerol spine undergo transesterification whereas free fatty acids separated from the spine undergo saponification reaction. The yield of the biodiesel depends on the FFA content present in the fat and is inversely proportional to each other. The yield of biodiesel reduced from 90.54-58.712% when the FFA% was increased from 5-33%[48]. The fat extracted from the skin of *Salmosalar* had a FFA of 0.4% at the time of extraction but increased as 4.5% because of auto oxidation in a time span of 120 days[49]. The moisture content in the animal fats often gets it converted in free fatty acid thus making it hard to rely on it as a reliable feedstock[35]. Any fat with FFA% less than 15%, is called as yellow grease because of its yellowish appearances, whereas the heavily oxidized fats with FFA% exceeding 15% is termed as brown grease which is brownish black in color. This yellow grease can be mixed with brown grease to reduce the overall FFA content of that fat[50]. High FFA content not only inhibits the alkaline or base catalyzed transesterification reaction but also leads to soap formation[48,51]. The most optimum water and free fatty acid content for beef tallow to get Trans esterified into biodiesel using sodium hydroxide were 0.06 and 0.5% w.t., respectively[52]. However, fat with FFA concentration of 43.3% can be reduced in single step esterification by using reagents like methanol-benzene, methanol-toluene and methanol-xylene in an optimal ratio of 0.8:1[53].

PRETREATMENT OF WASTE ANIMAL FATS

Fats whose FFA% exceeding more than 3%, must undergo necessary pretreatment before being carried out to transesterification reaction[54]. The unhydrolyzed triglycerides and FFA are esterified in order to form monoglycerides, which can be transesterified for biodiesel production. Commonly used acid catalyst, sulfuric acid is preferred for reducing the FFA% below 0.5-1%, before transesterified with any other catalysts[48]. The esterification reaction carried out on FOG (Fat, Oil and Grease) using sulfuric acid at 60°C for 4 h reduced the FFA concentration below 1%[55]. Similarly, bovine tallow was esterified with methanol for a 6:1 molar ratio in presence of 0.08% sulfuric acid as catalyst at 63°C[17]. A third step esterification reaction must be carried out for waste fats whose FFA concentration is greater than 40%[48]. Another effective method of reducing the concentration of FFA is re-esterifying using glycerolysis reaction. The pretreatment of fat can be avoided by subjecting the fat to a high pressure of 9000 KPa and high temperature of 240°C, where maximum yield is produced because of simultaneous esterification ad transesterification reaction for a 6:1 molar ratio[56].

Table 4: Compilation of transesterification reaction carried out by various researchers

Feedstock	Alcohol concentration	Catalyst concentration	Temperature (°C)	Reaction time	Stirring speed	References
FOG	20% (w/w) methanol	9 g KOH/L of fats	50	4 h	350 rpm	Sanford *et al.*[60]
Dairy cow fat	150 mL methanol/5 g fat	2.5 g H_2SO_4	50	24 h	130 rpm	Bhatti *et al.*[61]
Beef tallow	150 mL methanol/5 g fat	2.5 g H_2SO_4	60	6 h	130 rpm	Bhatti *et al.*[61]
Ireland method 1	22.5% methanol/50 g fat	1% KOH	60	2 h	300 rpm	Bhatti *et al.*[61]
Ireland method 2	33.5 mL methanol/120 g fat	1.8 g KOH	60	1 h	300 rpm	Bhatti *et al.*[61]
Ireland method 3	24 mL methanol/120 g fat	2.5 g KOH	60	1 h	300 rpm	Bhatti *et al.*[61]
Beef tallow	6:1 (methanol: oil)/800 kg fat oil	1.5% (w/w) KOH	65	3 h	400 rpm	Da Cunha *et al.*[62]
Bovine tallow	1:9 (oil: methanol)	0.5% NaOH	63	2 h	NA	Ribeiro *et al.*[17]
Animal fat	1:6 (oil: methanol)	2% NaOH	65	1 h	NA	Dhiraj and Mangesh[63]
Animal fat	1:6 (oil: methanol)	3% H_2SO_4	60	48 h	300 rpm	Canakci and Van Gerpen[64]
Animal fat	1:5 (w/w) (oil: methanol)	3% H_2SO_4	85	5 h	400 rpm	Fan and Burton[65]
Animal fat	1:6 (w/w) (oil: methanol)	1% NaOH	65	1 h	400 rpm	Fan and Burton[65]
Animal fat	1:6 (oil: methanol)	1% NaOH	60	50 min	6000 rpm	Lin and Li[66]
Animal fat	1:6 (oil: methanol)	0.5% NaOH	60	3 h	250 rpm	Altun *et al.*[67]
Beef tallow	1100 mL methanol/5 L fat	65 g KOH	60	90 min	600rpm	Sivakumar *et al.*[53]

TRANSESTERIFICATION OF WASTE ANIMAL FATS

Transesterification reaction aims in producing fatty acid alkyl ester with lower viscosity and enhanced calorific value, by reacting the triglycerides in fat/oil with alcohol in presence of catalyst[40]. The reaction kinetics involves in conversion of triglyceride into diglyceride followed by monoglycerides which eventually gets converted in fatty acid alkyl ester. Any alcohol with simple carbon chain (till pentanol) can be used as solvent for the reaction but the feasibility of reaction is achieved upon using alcohol like methanol and ethanol[57]. The yield of biodiesel is deeply affected by the Water content and FFA concentration present in the fat[35]. Residual glycerin as reaction byproduct can be used in pharmaceuticals whereas unreacted alcohol can be reused upon recovery. Apart from transesterification, the biodiesel can also be synthesized by employing thermal cracking[58] of fat, micro emulsions[59] and direct blending of fat with diesel[10]. But these methods are least preferred because of their impact on physicochemical properties of biodiesel[59] Table 4 summarizes the transesterification reaction carried out by various researchers on different waste animal fats.

SELECTION OF ALCOHOL AND OPTIMUM MOLAR RATIO

The yield of biodiesel is decided upon the type of alcohol used in the reaction and the calculated optimum molar ratio of that alcohol with respect to the triglyceride. The most commonly preferred solvents for transesterification reactions are short chained alcohols such as methanol, ethanol, propanol and butanol, where maximum yield of 96-98% ester are obtained using them[68]. For an effective yield, ideal molar ratio must be maintained at the initiation of reaction and same must be used throughout the reaction in order to avoid any deviation from the desired result. The optimum amount of the alcohol required for the reaction is calculated based upon the molecular weight of the fat that is being used for biodiesel production using the formula given below:

$$M\ (TG) = 92.09\text{-}3\text{+}3(M\ (HA))\text{-}17$$ [69]

Even though calculated molar ratio is used for reaction, an excess amount of alcohol must be used in order avoid any equilibrium condition or deficiency in alcohol due to prolonged heating during reaction. A higher yield of biodiesel can be achieved by employing actual molar ratio greater than theoretical molar ratio (15-35 moles per fatty acid). For methanol, an excess of 1.6 times of calculated amount was used for avoiding any backward reaction[57]. Maintaining higher molar ratio during reaction enhances contact between the reactants and also the solubility of glycerol thereby increasing its separation rate[70]. The reaction time depends on the length of carbon chain present in alcohol used as addition of every single CH_2 group increases the reaction time by two fold whereas the branched chain increases by four fold (equivalent to two single CH_2 group)[64]. The amount of excess alcohol added must be appropriate as the unwanted alcohol yield more amount of glycerol thereby reducing biodiesel yield[62]. The effectivity in reducing FFA% is based on the length of the carbon chain in alcohol used[48]. Figure 2 represents the maximum yields achieved for various molar ratios for an reaction time of 2 h with 1% catalyst concentration[71].

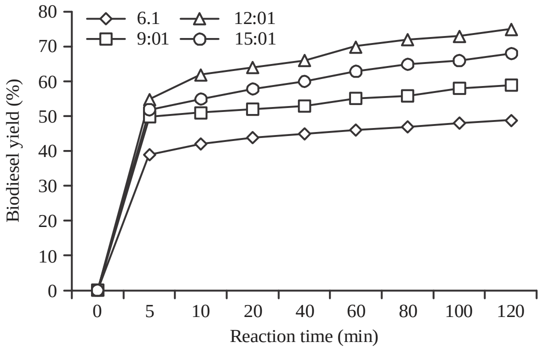

Fig. 2: Maximum yields achieved for various molar ratios for a reaction time of 2 h with 1% catalyst concentration[71]

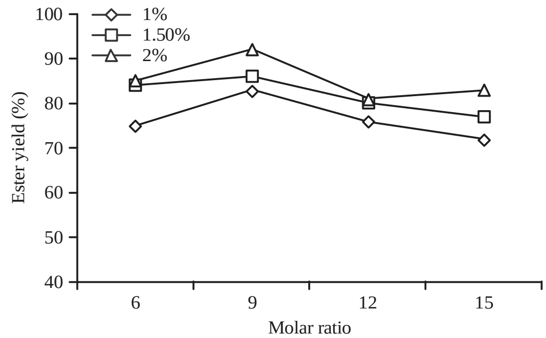

Fig. 3: Effect of KOH for various molar ratios between oil and methanol[71]

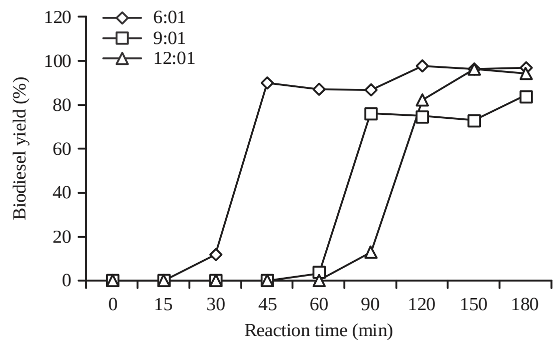

Fig. 4: Ester concentrations achieved for various reaction times for 1% catalyst concentration with varying molar ratios[71]

SELECTION AND INFLUENCE OF CATALYST

The conversion rate of triglycerides into fatty acid alkyl ester is improvised by using catalyst, which promotes the pace of the reaction. It is classified as homogeneous catalysts or heterogeneous catalysts based upon their existing phase and can be acidic, alkali or enzymatic. However, alkali catalysts always performs better among these catalyst because of its high chemical activity, low cost and easy availability[72], hence can be regarded as industrial scale catalyst for biodiesel production[73]. Simple and commercially available catalysts used in reaction are: Alkoxides[74], hydroxides[68], carbonates[75] and methoxides of sodium and potassium[76], sulfuric acid, hydrochloric acid[77] and sulfonic acid[78]. Presently improvised catalysts like earth metal compounds, metal silicates[69], anion exchange resins and organic catalysts like enzymes and guanidines heterogenized on organic polymers have been identified as effective catalysts with high reusabilityrate[79]. The phospholipids present in the fat inhibits the catalytic activity, thus degumming must be always carried out for animal fats which are extracted using hot rendering techniques[57]. Even though acid catalysts produce low viscous biodiesel[50], it is not much appreciated because of its poor reaction rate, requirement of high molar ratio and corrosion on engine parts[64]. Biodiesel produced using homogeneous catalyst makes glycerol separation tedious in addition to inability to recover it for reusing. Saponification of high FFA content can be avoided by using weak base catalyst where Aryee *et al.*[49] performed transesterification on fish oil using potassium phthalimide as weak base catalyst in presence of n-propanol. Heterogeneous catalysts are preferred to greater extent because of its easy availability and insolubility in reaction mixture[69] where methanoates and ethanoates of Sodium and potassium are the most commonly preferred Alkaline metal alkoxides, which are known for producing high yields (>98%) with low molar concentration (0.5%) for short time duration[80]. Potassium hydroxide was found to be most effective homogeneous catalyst for the biodiesel production from waste animal fat[29]. Figure 3 shows the effect of potassium hydroxide (KOH) as homogeneous catalyst, exhibited for various molar ratios between oil and methanol[71].

PREDICTION OF REACTION TEMPERATURE AND TIME

Generally, the temperature for transesterification reaction is decided based upon the type of feedstock used (oil or fat), melting point of the feedstock and boiling point of alcohol used. For an effective transesterification, the temperature must be maintained between 50-70°C, however acid catalyzed reaction must be maintained below 60°C in order to avoid burning of oil/fat, thereby reducing the biodiesel yield. Low reaction temperature provides lower reaction kinetics thereby increasing the catalyst concentration[61]. The reaction time is based on the operating temperature where the reaction carried out at elevated temperature was completed much early before the reaction carried out at room temperature[57]. However, higher yield of biodiesel can be achieved by maintaining the reaction at supercritical condition[64]. Figure 4 represents the Ester concentrations

Table 5: Effects of biodiesel on IC engines[81]

Issues encountered	Component affected	Origin of issue
Carbon deposition Wax and gum formation Soot formation	Cylinder bore and wall, piston head, oil and sealant rings, engine block head and injector spray tip	Oxidized biodiesel, improper combustions, high viscous biodiesel and blends
Parts corrosion	Supply and feed pump, high pressure injector pumps, fuel injector, nozzle and supply pipes	Water impurities, unwashed residues (acids, alcohols, catalysts, reaction byproducts)
Plugging, blocking and choking	Engine filter unit, fuel injector and nozzle	Presence of unreacted triglycerides, Diglycerides, monoglycerides, unwashed glycerine, solid and chemical contaminants, polymerized and polyunsaturated substances
Failure (swelling and cracking, softening and hardening of nitrile rubber) in lubrication and amorphous polymers (elastomers)	Rubber gasket, rubber sealing rings, rubber washers	Polymerization of elastomers by polyunsaturated vegetable oil based biodiesel, methanol
Performance failure due to cold condition	Supply lines, cylinder bore, spark plug	Low cetane number, Lower flash and fire point, high fuel viscosity

Table 6: Compilation of benefits of biodiesel

Advantages	References
Environmental concern	
Reduction in the quantity of waste being disposed	Hassan and Kalam[11]
Doesn't contribute to global warming	Jaichandar and Annamalai[72]
Nontoxic, biodegradable and easy handling and maintenance	Mekhilef *et al.*[82] and Ashnani *et al.*[83]
Carbon neutral fuel thereby decreasing the CO_2 level	Ashnani *et al.*[83]
Non flammable liquid	Jaichandar and Annamalai[72], Hassan and Kalam[11] and Atabani *et al.*[12]
Zero sulphur content and no aromatics	Hassan and Kalam[11] and Atabani *et al.*[12]
Reduced emission of hydrocarbons, CO, SO_2, polycyclic aromatic HC, nitric Polycyclic aromatic HC (nPAH), particulate matter (PM)	Dhiraj and Mangesh[63], Mekhilef *et al.*[82] and Ashnani *et al.*[83]
Performance and technology	
High fuel lubricity which improves the performance of fuel injector and pumps	Bhatti *et al.*[61] and Atabani *et al.*[12]
High engine performance with reduced engine parts wear and tear	Atabani *et al.*[12]
High cetane number and also reduces ignition delay	Van Gerpen[57], Hassan and Kalam[11] and Atabani *et al.*[12]
High oxygen content (oxygenated fuel)	Bhatti *et al.*[61], Dhiraj and Mangesh[63] and Jaichandar and Annamalai[72]
Reduction in carbon di oxide emission by 78% along with reduction in smoke during combustion	Atabani *et al.*[12] and Mekhilef *et al.*[82]
Easy and time effective synthesis than compared to petro diesel	Hassan and Kalam[11]
No need of adding lubricant since biodiesel itself has high clarity and purity characteristics	Hassan and Kalam[11] and Mekhilef *et al.*[82]
No complex process involved in production as that of in petro diesel	Hassan and Kalam[11] and Atabani *et al.*[12]
No modification of engine for fuel below B20, minor modification needed for B20 above	Hassan and Kalam[11], Atabani *et al.*[12] and Mekhilef *et al.*[82]
12% oxygen provides High combustion efficiency	Hassan and Kalam[11] and Atabani *et al.*[12]
Low pour point thus making it suitable for winter countries	Mekhilef *et al.*[82] and Ashnani *et al.*[83]
High flash point (110-170°C),safe transportation ensured	Hassan and Kalam[11], Atabani *et al.*[12] and Mekhilef *et al.*[82]
Social concern	
Increase in the gross income	
Reduces the% of fuel import with no import tax along with transportation	Atabani *et al.*[12], Mekhilef *et al.*[82] and Ashnani *et al.*[83]
Reduces the social demand of petro diesel in remote areas	Atabani *et al.*[12] and Mekhilef *et al.*[82]

achieved for various reaction times for 1% catalyst concentration with varying molar ratios[71].

REFINING OF BIODIESEL

Post reaction, the mixture gets separated because of variation in density gradient which makes the glycerol to get separated from biodiesel and settle down at bottom. Adding a smaller proportion of glycerol can be added to the separated biodiesel to remove unreacted Diglycerides (DGs) and Monoglycerides (MGs)[64]. Biodiesel obtained after final separation must be washed with hot water in order to remove any soluble impurities present in it[61]. Large scale separation is carried out using centrifuge[62], where biodiesel is completely separated from glycerol and is washed before drying.

EFFECT OF BIODIESEL[81]

Even though Biodiesel is widely appreciated as an effective substitute for ordinary diesel, it is not directly used in IC engine because of its corrosiveness due to acid catalyst, ability to degrade polymers[3]. Table 5 summarizes the effects of biodiesel on components of IC engine[81].

ADVANTAGES OF BIODIESEL

Biodiesel is commercialized globally because of its distinct features when compared to other synthetic petro fuels. Table 6 highlights the advantages of biodiesel in various aspects: Environmental concern, performance and technology and social concern.

CONCLUSION

Biodiesel has gained attention all over the world because of its robustness and self-sustain ability unparalled to any other renewable fuel. Waste animal fat can concluded as the most successful feedstock with low cost and higher potential. This righteous decision has solved numerous problems related to environmental concerns, waste disposal and handling and economy of fuel. On the other hand, production of biodiesel is dependent on Free Fatty Acid concentration, type of fat, molar ratio, catalyst concentration, reaction time and temperature which must be optimized for an ideal transesterification reaction. This paper has summarized various key points on biodiesel from waste animal fat in layman's approach and can help others in understanding for future study.

SIGNIFICANCE STATEMENT

This study identified waste animal fat as a potential feedstock for sustainable development with least environmental concerns. This study also aims in briefing various technical challenges involved in production of biodiesel from waste animal fats discarded from leather tanneries and animal slaughter houses. This study will serve as a fundamental reference for researchers working in biodiesel production to understand the concepts involved in it and acting as base for future works related in the field.

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