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STUDYING THE PROCESS OF OBTAINING BIODIESEL BY RECYCLING FOOD AND ANIMAL WASTE OILS

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Abstract: The agro-food industry generates large amounts of waste that contribute to environmental contamination. Animal fat waste constitutes some of the most relevant waste and the treatment of such waste is quite costly because environmental regulations are quite strict. Part of such costs might be reduced through the generation of bioenergy. Biodiesel constitutes a valid renewable source of energy because it is biodegradable, non-toxic and has a good combustion emission profile and can be blended up to 20% with fossil diesel for its use in many countries. Furthermore, up to 70% of the total cost of biodiesel majorly depends on the cost of the raw materials used, which can be reduced using animal fat waste because they are cheaper than vegetable oil waste. In fact, 6% of total feedstock corresponded to animal fat in 2019. Transesterification with alkaline catalysis is still preferred at industrial plants producing biodiesel. Recent developments in heterogeneous catalysts that can be easily recovered, regenerated and reused, as well as immobilized lipases with increased stability and resistance to alcohol denaturation, are promising for future industrial use. This manuscript reviews the available processes and recent advances for biodiesel generation from animal fat waste.

Introduction

Animal byproduct production, as part of the meat and poultry processing chain, is huge. For instance, it represents nearly 17 million tons per year only in the European Union.

Most of the waste results from over 328 million pigs, sheep, beef, goats and dairy cattle and 6 billion chickens, turkeys and other poultry that are slaughtered every year in Europe. After rendering, materials classified as edible which amount up to 12 million tons, are processed in a variety of food and feed related sectors. The remaining byproducts that are considered inedible have other applications for disposal such as biofuels and biodiesel for energy generation. It is energy generation, especially biodiesel production, that is one of the most attractive and expanding applications.

In this sense, the production of biodiesel guarantees a better profitability of inedible animal byproducts. Animal waste also consists of the organic matter resulting from the meat processing industry as well as from human consumption. Biodiesel consists of mono-alkyl esters of long chain fatty acids produced from oil or fat, but the use of vegetable oil adds a high price to biodiesel, and this has prompted the use of animal fats as an interesting alternative. In addition to its renewability, biodiesel also constitutes an attractive alternative because it offers better lubricating properties than fossil diesel fuel and it is biodegradable and non-toxic. It also has an improved cetane number and high flash point. Biodiesel also contributes to sustainability by reducing the carbon footprint due to lower CO2 emission compared to fossil diesel fuel.

Biodiesel can be used in existing diesel engines without the need for substantial modification. Biodiesel has a higher oxygen content than conventional diesel and the carbon to hydrogen ratio is also lower. This explains the major advantages of biodiesel such as lower emission of particulate matter, but also a lesser content of sulfur, hydrocarbon and carbon monoxide. The major challenge nowadays is the production of environmentally and economically viable biodiesel and the use of animal fat waste could contribute towards achieving this goal. This review is highlighting the latest advances in the available processes for biodiesel production from animal fat waste.

Animal Fats as Feedstock

About 328 million animals (cattle, sheep, pigs and goats) and 6 billion poultry (mainly chickens and turkeys) were slaughtered in 2014 in the European Union. Such a high number of slaughtered animals produces enormous amounts of waste animal residue including fats that need to be treated to reduce pollution or recycled to give them some added value. Such fats include beef tallow extracted from rendering fatty tissue of cattle, mutton tallow from rendering sheep, pork lard from rendering pigs and chicken fat from rendering feathers, blood, skin, o al and trims. The wet rendering process includes the presence of water and fats heated below 49 C. The goal is separation of the fat from the protein fraction. Other fats are those resulting from meat and the meat processing industry and those from recycling of the industrial cooking business.

Such recycled greases that are produced from heated animal fats collected from commercial and industrial cooking can be classified as yellow grease and brown grease depending on the content of free fatty acids (FFA). Yellow grease is considered if FFA < 15% by weight and brown grease when FFA > 15%.

Typical fatty acid composition of pork lard, beef tallow, mutton tallow and poultry fats are shown in Table 1. There is a wide variety depending on the animal species but in general, they contain common types of fatty acids, most of them having 16 to 18 carbons.

Most relevant fatty acids are palmitic (16:0) and stearic (18:0) acids as saturated fatty acids(SFA);oleic acid(18:1)as monounsaturated fatty acids (MUFA); and linoleic (18:2) and arachidonic (20:4) acids as polyunsaturated fatty acids (PUFA) [32]. Due to their high content of saturated fatty acids (near 40% SFA), ruminant and pig fats are predominantly solid while those from chicken fat (nearly 30–33% of saturated fatty acids) are almost liquid or in semi-solid form [33]. Therefore, it must be taken into account that raw animal fats are mostly in a solid state at ambient temperature and therefore, preheating at 45 C is required for their use as fuel for diesel engine [14]. Further, such high content in saturated fatty acids generally results in more stable biodiesel with high cetane numbers (more than 50 for lard and tallow).

One of the main applications of inedible animal fat byproducts is the production of biodiesel. Inedible animal byproducts are structured into three categories with in the EU that are defined according to their risk to human or animal health. Category 1 has the highest risk, Category 2 still offers a high risk, while Category 3 offers the lowest risk and is fit for human consumption although generally not used for human food because of its non-edible content or for commercial reasons. Major uses for Category 3 byproducts are as feed and pet food. In any case, fats from all three categories can be destined to biodiesel production and some stakeholders have reported that Category 3 provides better quality for biodiesel production. Nearly 81% of caul and lung fat and 26% of cod and kidney, knob and channel fat from cattle are destined for biodiesel production. In the case of sheep fats, 88% of caul fat, 43.3% of lung fat and 67.1% of knob and channel fat are destined for biodiesel production. In 2019, the total amount of vegetable oil and animal fat used as feedstock for biodiesel exceeded 13 million tons in the EU. From them, 800 thousand tons (6% of total feedstock) corresponded to animal fats, and such amount has remained fairly constant since 2014. In the case of the US, animal fats represented 8.4% of total feedstock and were poultry fat, tallow and white grease with amounts of 74, 132 and 243 thousand tons, respectively.

Table 1. Typical composition in major fatty acids (as % of total fatty acids) of pork, beef, mutton and chicken fats.

Fatty Acid		Pork Lard	Beef Tallow	Mutton Tallow	Poultry Fat
		[37]	[38]	[39]	[40]
Myristic	C14:0	1.6	1.6	2.2	0.4
Palmitic	C16:0	25.1	21.6	21.1	21.6
Stearic	C18:0	12.6	17.7	11.6	6.3
Palmitoleic	C16:1	2.8	2.5	2.1	3.2
Oleic	C18:1	36.5	31.5	38.7	30.0
Linoleic	C18:2	16.5	3.3	10.2	28.4
Linolenic	C18:3	1.1	1.3	0.6	2.4
Arachidonic	C20:4	0.3	-	-	3.4
Docosapentaenoic	C22:5	0.2	-	-	0.3
Docosahexaenoic	C22:6	-	-	-	0.8
Total saturated	SFA	39.4	49.1	40.4	29.1
Total monounsaturated	MUFA	39.7	41.0	47.1	33.2
Total polyunsaturated	PUFA	20.9	10.0	12.5	37.6

Transesterification for Producing Biodiesel from Animal Fats

The major steps in the production of biodiesel from animal fat waste are shown in Figure1. A pretreatment is needed because feedstocks like animal fats usually contain a high amount of free fatty acids (FFA) and water which reduces the yield of biodiesel and increases production costs because of the difficulty of separation and purification. Biodiesel is produced through the transesterification reaction of a fat with as hort-chain alcohol in the presence of acatalyst. Different catalysts are available to be used for biodiesel production.

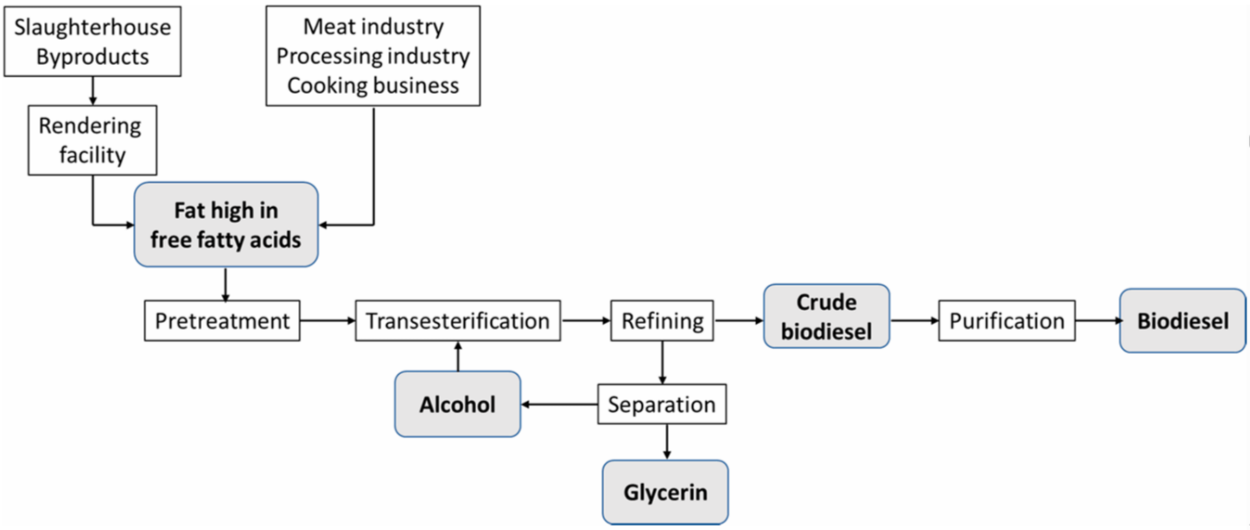

Figure1.Major steps in the production of biodiesel from animal fat waste.

Table2. Examples of operating conditions during the transesterification step for the production of biodiesel from animal fat waste.

Animal Fat	Catalyst	Weight (% to Fat)	Reaction Yield (%)	Alcohol:Oil Ratio	Operating Conditions	References
Beef tallow	KOH	0.8	90.8	6:1	60 °C, 2 h	[57,58]
Pork Lard	KOH	0.8	91.4	6:1	60 °C, 2 h	[57,58]
Poultry fat	KOH	0.8	76.8	6:1	60 °C, 2 h	[57,58]
Chicken waste	KOH	1	-	6:1	60 °C, 2 h	[59]
Duck tallow	KOH	1	97.1	3:1	65 °C, 3 h	[60]
Pork fat	KOH	0.5	97.3	6:1	65 °C, 2 h	[61]
Catfish fat	KOH	0.8	92.7	6:1	50 °C, 0.75 h	[62]
Chicken fat	KOH	0.8	82.0	8:1	60 °C, 1 h	[63]
Swine lard	KOH	1.1	98.0	7.4:1	65 °C, 3 h	[64]
Mutton fat	MgO-KOH	20	98.0	22:1	65 °C, 20 min	[65]
Chicken fat	H_2SO_4	1.25	99.0	1:30	50 °C, 24 h,	[24]
Mutton tallow	H_2SO_4	1.25	93.2	1:30	60 °C, 24 h	[24]
Chicken fat	NaOMe	1	88.5	6:1	60 °C, 4 h	[66]
Chicken fat	Nano CaO	1	88.5	9:1	60 °C, 5 h	[67]
Chicken fat	Composite membrane & NaOMe	1	98.1	1:1	70 °C, 3 h	[68]
Chicken fat	$CaO/CuFe_2O_4$	3	94.5	15:1	70 °C, 4 h	[69]
Lard	35%CaO/zeolite	8	90.9	30:1	65 °C, 1.25 h	[15]
Chicken fat	$AC/CuFe_2O_4$ encapsulated with CaO	3	95.6	12:1	65 °C, 4 h	[70]
Brown grease	Mesoporous silica diphenylammonium triflate	15	98.0	15:1	95 °C, 2 h	[71]
Brown grease	ZnO/ZrO2	0.8	78.0	1:1.5	200 °C, 2 h	[72]
Lard	Supercritical methanol	-	89.9	45:1	335 °C, 20 MPa, 15 min Agitation 500 rpm	[73]
Waste lard	Immobilized lipase from *Candida antarctica*	6	96.8	6:1	50 °C, 30 min Ultrasound assisted	[74]

Biodiesel has to comply with regulations EN14214 from the European Committee of Standardization (ISO) and the ASTM6751-3 from the American Society for Testing and Materials (ASTM). There are relevant benefits in the use of biodiesel produced from animal fats, such as the emission of polycyclic aromatic hydrocarbons being reduced by 75–90% and total unburned hydrocarbon by 90% when using biodiesel produced from animal fats when compared to conventional diesel

Conclusions

Biodiesel produced from agricultural waste has been rapidly expanded around the world due to its relevant advantages such as being biodegradable, renewable and sulphur-free. The cost of biodiesel majorly depends on the cost of the raw materials being used, with animal fat waste being cheaper than vegetable oil waste. Animal fats, usually found as waste from slaughterhouses, the meat processing industry, and cooking facilities, can be used as feedstock for biodiesel production. As reported in this manuscript, there are numerous processes already available for the production of biodiesel from animal fats and operating conditions during transesterification. There are also alternative solutions for pretreatment which mainly depend on the moisture and FFA content of such residues. Alkaline catalysis is still preferred at industrial plants producing biodiesel because it is faster than acid catalysis and cheaper than most alternative catalysts including acid catalysts and lipases.

Although much research has been published on heterogeneous and acid and enzyme catalysts which avoid the challenges of water and FFA in animal fats, biodiesel producers have not yet adopted these technologies. However, there are recent developments that are promising for future industrial use. This is the case with heterogeneous catalysts that can be easily recovered, regenerated and reused, and immobilized lipases that improve e ciency and reduce costs by increasing enzyme stability and making the enzyme more resistant to denaturation by alcohol.

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