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REVIEW ARTICLE

Exploitation of Meat Industry By-products for Biodiesel Production: Pakistan's Perspective

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ABSTRACT

Fossil fuels including coal, natural gas and petroleum constitute predominant sources for the acquisition of energy. Due to the rapid depletion and continuously increasing demand of these fuels, exploration of renewable substitutes is gaining momentum across the world. Biodiesel represents a biodegradable and renewable alternative to conventional petroleum-based fuel. Furthermore, it has been implicated to reduce the likely emission of hydrocarbons, carbon monoxide and particulate matter. Residual animal fats (a by-product of meat industry) can be efficiently converted into biodiesel through the process of transesterification. On account of tremendous meat-producing potential, the deployment of residual animal fats for biodiesel production could be quite auspicious for Pakistan. It will not only be a waste management process, but removal of accessory fats will also improve the quality of meat. Besides saving ample foreign exchange, it may help to reinforce the prospects for socio-economic development.

INTRODUCTION

Fuel sources can be divided into two distinct classes; fossil fuels and renewable fuels. Fossil fuels are among the non-renewable sources and were originated from enormous deposition of CO_2 during ancient geological age. Major fossil fuel sources are natural gas, coal and petroleum. Although fossil fuels continue to fulfill over 80% of global energy requirements, the trend towards novel energy sources is drawing attention across the world particularly in non-oil producing countries. Worldwide, oil, coal and natural gas provide respectively 43%, 40% and 17% of energy that is produced by fossil fuels. Among fossil fuels, oil is on the verge of depletion. The locomotion of goods and freight is usually based upon the use of diesel trucks, establishing it as a key fuel player in the economy of Pakistan. The demand for diesel fuel is constantly increasing, requiring its alternate that could be sustainable, technically feasible, price competitive and ecologically acceptable. Politico environmental situation, emission of huge amounts of greenhouse gases, health problems, economic concerns, cost effectiveness as well as predicted shortage of conventional fuels, direct towards the exploration of alternative fuel to drive diesel engines. Renewable essentials such as biomass, wind, solar energy and hydropower will play a significant role in the future. By next 25 years half of the energy supply and 80% of the global electricity generation will be shifted to renewable sources (EWEA, 2005; EREC, 2006). Biodiesel is the substitute fuel that can be synthesized from renewable lipid materials such as vegetable oil or animal fats. Biodiesel has been approved by the environmental protection agency (EPA) as renewable fuel as well as an additive for fossil fuel. It can be blended with petroleum diesel, or can be used in pure form (Da Cunha et al., 2009).

Global biodiesel production scenario

Unlike developing countries, the production of biodiesel has gained commercial status in many advanced countries. Countries responsible for more than 80% of global biodiesel production, consume animal fats as much as 20% of total feedstock (Balat and Balat, 2010). In 2008, approximately 10% of global biodiesel was produced from rendering products (Banković-Ilić et al., 2014). About 90% of Canadian biodiesel was generated from animal fats, while in USA; almost 8–10% of rendered fats are converted into biofuels (Banković-Ilić et al., 2014). Beef tallow represents 17% of total feedstock employed in the Brazilian biodiesel generation (ANP, 2012). Usage of expensive substrates for biodiesel production keeps the cost higher. Low-cost feedstock such as waste animal fat can make economically viable biodiesel (Bhatti et al., 2008). Although animal-derived fats have gained considerable attention across the world for the production of biodiesel, relatively few studies have been conducted in Pakistan to attract meat sector towards biofuel generation. This manuscript aims to provide valuable information concerning biodiesel production using low-cost, meat industry byproducts.

Tendency of animal fat for biodiesel production

Fats are hydrophobic substances consisting of one mole of glycerol and three moles of fatty acids and are thereby referred to as triglycerides. Fats deposited in animal tissues can be extracted and used for various beneficial purposes. The by-products of meat industry are subjected to the process of rendering for the extraction of residual fats (Romans et al., 2001). Meat processing plants usually have discrete rendering facilities for edible and inedible fats. Edible fats are utilized to synthesize margarine and cooking fat while inedible fats are consumed in animal feed. Contrary to vegetable oils, animal fats contain huge amount of saturated fatty acids which impart high oxidative stability (Lebedevas et al., 2006). Animal fats are categorized into three distinct types. High quality fat has less than 2% of free fatty acids and is generally used to synthesize drugs and cosmetics. Medium and low-grade fats exhibit 3-5% and above 5% free fatty acids respectively and can be effectively used for biofuel production.

Animal-derived feedstock used for biodiesel production

Beef fat, lard, poultry fat and fish oil constitute the chief products of animal origin primarily used for biodiesel production (Encinar et al., 2011). Additionally, feather meal, duck fat, lamb fat and leather industry fleshing wastes can also be used as feedstock to generate biodiesel. Tallow represents a rendered form of beef or mutton fat that remains solid at ambient temperature and can be used in producing biodiesel. Table-1 illustrates various types of animal-derived feedstock successfully used for biodiesel production. The conversion of low quality residual animal fats derived from slaughterhouses into commercial grade biodiesel could help to reduce environmental contamination besides contributing to overcome the fuel crisis (Janaun and Ellis, 2010).

Techniques for biodiesel production

Generally biodiesel is generated through transesterification of animal fats, which can be classified into catalyzed (using various chemical catalysts), enzymatic methods and non-catalyzed (supercritical alcohol conditions) reactions. The fats/oils are chemically esterified with an alcohol such as methanol or biochemically with an enzyme (Hemmat et al., 2013). Chemical reactions are usually catalyzed by a strong base such as sodium hydroxide or potassium hydroxide. Supercritical trans-esterification is performed at extremely high temperature and pressure conditions. The obtained esters constitute biodiesel, which is decomposable and excellent option from the ecological standpoint.

Table 1: Various types of animal-derived feedstock used for biodiesel production

Animal-derived feedstock used for biodiesel production	References
Beef tallow	Alcantara et al. (2000)
	Moraes et al. (2008)
	Soldi et al. (2009)
Mutton tallow	Bhatti et al. (2008)
Beef and mutton fats	Ali et al. (2012)
Lamb fat	Al-Zuhair et al. (2012)
Poultry fat	Liu et al. (2007)
	Jagadale and Jugulkar (2012)
Feather meal fat	Kondamudi et al. (2009)
Duck tallow	Chung et al. (2009)
Lard	Dias et al. (2009)
	Jeong et al. (2009)
	Berrios et al. (2009)
Leather industry wastes	Ísler et al. (2010)
Leather industry fleshing waste	Getahun and Gabiyye (2013)
Leather industry tannery waste	Kolomaznik et al. (2009)
Crude fish oil	El-Mashad et al. (2008)
	Lin and Li (2009)
	Wiggers et al. (2009)
Catfish fat	Huong et al. (2011)

Extraction of fats

Fat is extracted from the sample through various methods depending on the source nature and quality. For instance, feather meal sample is melted in water at 70 °C for the extraction of fats (Kondamudi et al., 2009). The superficially floating fat is transferred and centrifuged to collect the fat content for the removal of free fatty acids by mixing with a basic solution of potassium hydroxide. Further processing is performed for the purification of fats. Dry and purified fat can be obtained by cooking the samples at 110 °C (Hemmat et al., 2013). The moisture and wastes are completely removed through this process. Poultry fats can also be heated at a temperature higher than 100 °C and then filtered under vacuum to remove suspended matter (Lopes, 2011). Removal of dust particles with water followed by melting at 100 °C for 90 minutes to extract oil from animal fats is also advised (Ali et al., 2012). A combined procedure for constant fat extraction with subsequent enzymatic production of biodiesel from lamb meat in supercritical CO_2 has been developed by Al-Zuhair et al. (2012). Getahun and Gabiyye (2013) used an extractive boiler joined with heater to obtain oil from the flesh.

Table 2: Various transesterification methods used for biodiesel production

Type of transesterification	Catalyst/ Enzyme	Reaction temperature	Reference
Homogeneous one-step	Potassium hydroxide	65°C	Moraes et al. (2008)
Homogeneous one-step	Potassium hydroxide	55–85°C	Chung et al. (2009)
Homogeneous one-step	Potassium hydroxide	65°C	Da Cunha et al. (2009)
Homogeneous one-step	Potassium hydroxide	24.8–75.2°C	Jeong et al. (2009)
Homogeneous one-step	Sodium hydroxide	20 °C	Liu et al. (2011)
Homogeneous two-step	Sulphuric acid + $NaOCH_3$	60°C	Canakci and Gerpen (2001)
Homogeneous two-step	Sulphuric acid + Sodium hydroxide	50–70 °C	Guru et al. (2009)
Homogeneous two-step	Sulphuric acid + Sodium hydroxide	55-65°C	Math et al. (2010)
Homogeneous two-step	Sulphuric acid + Potassium hydroxide	60°C	Alptekin et al. (2012)
Homogeneous two-step	Sulphuric acid + Potassium hydroxide	60°C	Panneerselvam and Miranda (2011)
Heterogeneous one-step	Calcium oxide	23–25°C	Venkat et al. (2006)
Heterogeneous one-step	$Mg_6Al_2(CO_3)(OH)_{16}4H_2O$	60–120°C	Liu et al. (2007)
Heterogeneous one-step	Sulfonated polystyrene	64°C	Soldi et al. (2009)
Heterogeneous two-step	Diarylammonium + $NaOCH_3$	50–9 °C	Ngo et al. (2010)
Enzyme-catalyzed	Burkholderia cepacia lipase	50°C	Da Rós et al. (2012)
Enzyme-catalyzed	Candida antractica lipase	50 °C	Huang et al. (2010)
Enzyme-catalyzed	Mucor meihei lipase	25–65°C	Aryee et al. (2011)
Supercritical	-	350–400°C	Marulanda et al. (2009)
Supercritical	-	300–400°C	Marulanda et al. (2010)
Supercritical	-	320–350°C	Shin et al. (2012)

Transesterification process

The most frequently used method to generate biodiesel from animal fats is transesterification process, which is further categorized into homogeneous, heterogeneous, enzyme-catalyzed and non-catalyzed (supercritical alcohol conditions) reactions (Banković-Ilić et al., 2014). One-step and two-step transesterification reactions are applied to feedstock with low and high acid numbers, respectively (Chakraborty et al., 2014).

Homogeneous reactions generally involve alcohol: fat molar ratio of 6:1, catalyst concentration of about 1% and reaction temperature of 60 °C for 1 h. Sulfuric acid constitutes the most commonly used acid catalyst whereas both KOH and NaOH are typically used as base catalysts for homogeneous transesterification (Chakraborty et al., 2014). Heterogeneous transesterification involves comparatively high catalyst concentration and reaction temperature with longer reaction time than its homogeneous equivalent. Regardless of being a time-consuming procedure, enzymatic transesterification can be conveniently used for the processing of feedstock having high acid number without acid pre-treatment. Supercritical transesterification is considered as economically prejudicial due to involvement of extremely high temperature and pressure conditions. Although both homogeneous as well as heterogeneous transesterification methods are currently being applied for the successful conversion of animal fats into biodiesel, introduction of novel techniques using ultrasonic irradiation, microwaves, enzymes and radio-frequency heating will further extend the global biodiesel production from animal-derived byproducts.

Purification of biodiesel

After the transesterification process, the biodiesel is separated from the byproducts produced in reaction mixture. Biodiesel was collected after overnight cooling at room temperature. The glycerin settled in bottom layer and was easily separated from the biodiesel. The superficial layer containing biodiesel was washed with warm water and then with acidified water (Kondamudi et al., 2009; Hemmat et al., 2013). Ma et al. (1998) washed methyl esters of beef tallow with warm water in an equal amount. They distilled biodiesel under vacuum at 80 °C for complete removal of water, and then esters were winterized at 20°C for 24 h to exclude glyceride residues. (Altuna et al., 2010) separated methyl esters phase from the bottom glycerol phase then washed with hot water. After clearing the glycerol phase, ester phase was washed with hot water supplemented with phosphoric acid to eliminate other byproducts. Biodiesel was heated at 105°C for 30 min to eliminate water (Da Cunha et al., 2009).

Food versus fuel

By means of continuous efforts to produce biodiesel from non-food sources, it has been established that fats produced as a waste in slaughterhouses offer a promising feedstock. The raw material of animal fat-derived biodiesel is rejected for food, so its use for biodiesel production offers an added environmental perspective. It can avoid disposal problem in slaughterhouses by minimizing the environmental impact associated with the accumulation of these residues. The economics of biodiesel production totally depend upon the cost of utilized feedstock. Therefore high vegetable oil prices are very unfavorable, whereas non-food, waste animal fats could solve the problem of the biodiesel industry by frequently providing inexpensive and abundant, high-quality feedstock.

Cost of biodiesel production

Cost of biodiesel production majorly depends on the procurement price of substrate (fats/oils) used in transesterification process. Chakrabarti et al. (2012) had reported the prices of biodiesel production from different plant oils. Cost of biodiesel remained Pakistani rupees 94.54, 162.70, 277.00 per liter from Jatropha oil, Castor oil and Taramira oil, respectively. Bhatti et al. (2008) confirmed that chicken and mutton fats were appropriate, inexpensive feedstock for biodiesel production.

Potential animal fat production in Pakistan

Owing to extensive livestock population, Pakistan has tremendous potential for meat production. Cattle, buffaloes, camels, sheep, goats, poultry and fish are raised for meat purpose. Besides mutton and beef, chicken, quail and fish are also consumed for meat production while farming of ducks, turkeys, rabbits and ostriches is relatively uncommon. Pakistan produced 3379 hundred tones of meat and 248.8 hundred tones of animal fats in fiscal year 2012-13 (Anonymous, 2013). This recorded meat production corresponded to 1829 hundred tones of beef, 907 hundred tones of poultry and 643 hundred tones of mutton (Anonymous, 2013). The conversion of low quality residual animal fats (derived from meat industry) into commercial grade biodiesel could help to reduce environmental contamination besides contributing to overcome the fuel crisis (Janaun and Ellis, 2010).

Limitations in biodiesel production from waste animal fats

The major technical constraints associated with processing of waste animal fats include the presence of relatively high content of water, free fatty acids, saturated fatty acids, phosphoacylglycerols and pathogens. Dessication, drying or gravitational settling can be used for the exclusion of excessive humidity. Two-step acid/base transesterification helps to cope with the relatively high concentration of free fatty acids (Sawangkeaw and Ngamprasertsith, 2013). Compared to vegetable oils, animal fats contain high amount of saturated fatty acids which diminish the efficacy of resultant biodiesel in cold weather. Nevertheless this problem can be overcome by suitable additives or winterization process (Lebedevas et al., 2006). Phosphoacylglycerols can be eliminated from animal fats through degumming process using 60% orthophosphoric acid followed by centrifugation (Canoira et al., 2008). Pathogenic prions involved in the contamination of biodiesel thereby offering a risk towards the environment and public health could be effectively inactivated via esterification at high temperature catalyzed by sulfuric acid (Seidel et al., 2006).

Conclusions and Recommendations

Virtually 20% of Pakistan’s foreign exchange is spent to import fossil fuels. The use of waste material for biodiesel production will considerably reduce the production cost and facilitate the optimal waste disposal without competing with food market. A wide range of residual fat sources from slaughterhouses is readily available in Pakistan for deployment in biodiesel synthesis. Trans-esterification of animal fats has been successfully carried out under experimental conditions in Pakistan. Further research emphasizing on the production of biodiesel using animal fats is requisite to ascertain sustainable development and curtail the dependence on imported fuel.

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