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Biodiesel production from vegetable oil and waste animal fats in a pilot plant

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ABSTRACT

In this study, corn oil as vegetable oil, chicken fat and fleshing oil as animal fats were used to produce methyl ester in a biodiesel pilot plant. The FFA level of the corn oil was below 1% while those of animal fats were too high to produce biodiesel via base catalyst. Therefore, it was needed to perform pretreatment reaction for the animal fats. For this aim, sulfuric acid was used as catalyst and methanol was used as alcohol in the pretreatment reactions. After reducing the FFA level of the animal fats to less than 1%, the transesterification reaction was completed with alkaline catalyst. Due to low FFA content of corn oil, it was directly subjected to transesterification. Potassium hydroxide was used as catalyst and methanol was used as alcohol for transesterification reactions. The fuel properties of methyl esters produced in the biodiesel pilot plant were characterized and compared to EN 14214 and ASTM D6751 biodiesel standards. According to the results, ester yield values of animal fat methyl esters were slightly lower than that of the corn oil methyl ester (COME). The production cost of COME was higher than those of animal fat methyl esters due to being high cost biodiesel feedstock. The fuel properties of produced methyl esters were close to each other. Especially, the sulfur content and cold flow properties of the COME were lower than those of animal fat methyl esters. The measured fuel properties of all produced methyl esters met ASTM D6751 (S500) biodiesel fuel standards.

1. Introduction

Biodiesel has received significant attention in all countries since it is nontoxic, biodegradable and renewable diesel fuel. Biodiesel is generally produced from cooking vegetable oils. Using high-quality virgin oils makes biodiesel more expensive than diesel fuel and it causes to increase in vegetable oil prices. Therefore, low cost feedstocks are needed and should be used in biodiesel production. In Turkey, B2 (2% biodiesel, 98% diesel fuel) usage is excise tax free for biodiesel produced from waste cooking vegetable oils. However, there are different biodiesel feedstocks to be used in the production. For example, rendered animal fats and leather industry wastes are appealing feedstocks to produce biodiesel so that there is no conflict with food production.

Chicken fat is a low cost feedstock for biodiesel production compared to high-grade vegetable oils. It is extracted from chicken wastes such as chicken feathers, blood, offal and trims after rendering process. Especially, chicken slaughterhouses not having a rendering plant have waste disposal problems. These wastes can be evaluated in chicken fat producing. The chicken fat potential in Turkey is considerably high. The number of chicken consumption was about 1200 million in 2013 (TSI, 2014). If it is assumed that 25% of chicken amount are sent to rendering process and the fat contents of rendering products are 10–12%, there will be about 100 million kg of chicken fat per year. Leather industry wastes are another feedstock for biodiesel production. Turkish leather industry has taken a prominent place in the world leather trade with its high export productivity. The number of animal skin production was about 10 million in 2013 (TSI, 2014). The leather industry is one of the considerably polluting industries and it produces highly quantity of fat-originated solid and liquid wastes while processing hides and skins (Ravindran and Sekaran, 2010). Most of the solid waste in the leather production process is originated during the fleshing procedure to remove flesh and natural fats from the hides and skins (Pecha et al., 2012). The fat content

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of leather industry wastes is remarkable. However, these wastes are not evaluated effectively and there is almost no application method to recover them. One way to recover the leather industry wastes is using them as feedstock in the biodiesel production due to their rich fat content (Çolak et al., 2005; Ozgunay et al., 2007a, b; İşler et al., 2010).

The pollution caused by the meat industry wastes increases with the growing annual meat consumption. It may be reduced and more valuable products can be obtained by converting them to biodiesel. However, these waste oils and fats often contain significant amounts of free fatty acid (FFA). FFAs may diminish the biodiesel yield and complicate the biodiesel production because they react with conventional alkaline catalysts such as potassium and sodium hydroxide, and soaps are produced by this reaction. Soaps prevent the separation of the ester, glycerin and wash water (Canakci and Van Gerpen, 1999). Therefore, some additional processes are required to get high biodiesel yield and standard biodiesel fuel.

The FFA levels of the vegetable oils are generally lower than 1% level while the FFA level of the rendering plant feedstock is generally between 5% and 25% (Canakci and Van Gerpen, 2001). The researchers have suggested that the FFA level of the feedstock should be reduced to less than 1% before using an alkaline catalyst (Freedman et al., 1984; Liu, 1994). One way to recover the FFAs is converting them to esters by using acid catalysts such as sulfuric acid (Canakci and Van Gerpen, 2001) or strong base catalysts such as tetramethylammonium hydroxide (Kolomaznik et al., 2009). The acid catalysts are cheap and quite effective for converting FFAs to esters. In biodiesel production, the acid-catalyzed process is generally called as pretreatment. FFAs are converted to esters through the pretreatment of the feedstock with high FFA and thereby the FFA level reduces.

Many researches were performed on producing biodiesel from waste vegetable oils and animal fats in laboratory scales (Kolomaznik et al., 2009; Sabudak and Yildiz, 2010; Bhatti et al., 2008). However, there are a partial number of studies on animal fats especially with high FFAs in a pilot plant scale. Cunha et al. studied (Cunha et al., 2009) the process of biodiesel production in a pilot plant using beef tallow as biodiesel feedstock. The FFA value of the beef tallow was about 0.75% on average. Therefore, it was converted to biodiesel by transesterification reaction. They used potassium hydroxide and methanol in the production. They concluded that the alkaline transesterification of beef tallow produced high quality biodiesel with a good conversion rate. Canakci and Van Gerpen (2003) evaluated two different animal fats with 9% (yellow grease) and 40% (brown grease) FFA for biodiesel production in a pilot plant. After reducing the FFA level of the animal fats by two step pretreatment with acid catalyst, they produced biodiesel by transesterification reactions via alkaline catalyst. The total and free glycerin values of the animal fats biodiesels were suitable to the biodiesel standards. Chitra et al. (2005) selected jatropha curcus oil with 3.1% FFA for biodiesel production. After having optimized concentration of methanol and NaOH in laboratory scale experiments, the studies on large scale production of biodiesel were performed in the biodiesel pilot plant. According to large scale biodiesel production results, the average biodiesel yield was obtained as 96%. The kinematic viscosity and specific gravity of the jatropha biodiesel were found to be within the limit of biodiesel standards.

In the previous studies (Alptekin and Canakci, 2010, 2011; Alptekin et al., 2012), optimum reaction parameters were investigated to produce biodiesel from fleshing oil and chicken fat. These studies showed that FFA level of the high free fatty acid feedstock could be decreased to below 1% in laboratory conditions. After finding the optimum reaction parameters for small-scale transesterification of feedstocks, a pilot scale biodiesel production from animal fats were aimed. The purpose of the present study is to produce biodiesel from vegetable oil and animal fats with high free fatty acid in a biodiesel pilot plant. Therefore, the biodiesel production processes in a pilot scale were investigated with corn oil, fleshing oil and chicken fat. The obtained methyl esters were characterized by determining their fuel properties according to the standard test methods, and fuel properties of the produced methyl esters were compared to each other and biodiesel standards.

2. Materials and methods

In this study, corn oil, chicken fat and fleshing oil were used as feedstocks for biodiesel production. Corn oil was supplied from a local market. The fleshing oil was obtained from the solid wastes recycle plant in Istanbul Leather Organized Industry in Istanbul, TURKEY. It is known that there are two kinds of original fleshing which are green fleshing and lime fleshing (Sundar et al., 2011). In this study, lime fleshing oil was used. Chicken fat was acquired from Beypiliç Chicken Slaughterhouse in Bolu, TURKEY. These animal fats are transformed into liquid form by a rendering process. The corn oil and chicken fat were liquid at room temperature while the fleshing oil was in solid state at room temperature.

The initial target for the pretreatment is to reduce the FFA level of feedstocks to less than 1%. Because the acid values of the animal fats used in this study were greater than 2 mg KOH g^{-1}, it was needed to perform a pretreatment to the feedstocks. Due to low acid value of corn oil, it was directly subjected to transesterification via base catalyst. Some measured properties of the oils are shown in Table 1. The fatty acid compositions of the oils and methyl esters are given in Table 2, which are important for the determination of the mass balance in the process. According to fatty acid compositions of the feedstocks, the total saturated fatty acid compositions of corn oil, chicken fat and fleshing oil are about 14%, 27% and 42%, respectively. On the other hand, saturated fatty acid rates in the produced methyl esters remained almost the same when compared with the respective feedstocks.

2.1. Pretreatment and transesterification process in the pilot plant

The optimum reaction parameters of small-scale transesterification of feedstocks were used in a pilot scale biodiesel production from animal fats (Alptekin and Canakci, 2010, 2011; Alptekin et al., 2012). In addition, corn oil was used in pilot scale biodiesel production to compare the fuel properties of vegetable oil and animal fats methyl esters. The biodiesel pilot plant was assembled at the Alternative Fuels Research and Development Center in Kocaeli University. Biodiesels were produced in the pilot plant with the capacity of about 100 kg per day. The schematic of the biodiesel pilot plant is shown in Fig. 1. The feedstock tank (200 l) has electrical heaters to prevent solidification of feedstock especially for fleshing oil. All the feedstocks were filtered with 60-micron fuel filter before transferring to feedstock tank.

Sulfuric acid and methanol were used for the pretreatment of the fleshing oil and chicken fat. Certain amounts of the feedstock were transferred to main reaction (120 l) tank for pretreatment reactions. The feedstock was dried under vacuum to remove any potential water. The required amount of alcohol was transferred from the alcohol tank (200 l) to methoxide tank (120 l). The acid catalyst was added to the tank manually. Methanol and catalyst were mixed in the tank named as methoxide tank. The reactant amounts differ from each other due to different FFA levels of the feedstocks and those will be mentioned in the next sections. The alcohol and catalyst mixture were stirred about 20 min in the methoxide tank and then it was transferred to the reaction tank when the temperature of the feedstock in the reaction tank