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Biodiesel Production from Broiler Chicken Waste

John Abraham, Ramesh Saravana Kumar, Francis Xavier, Deepak Mathew

***Abstract*—**Broiler slaughter waste has become a major source of pollution throughout the world. Utilization of broiler slaughter waste by dry rendering process produced Rendered Chicken Oil (RCO), a cheap raw material for biodiesel production and Carcass Meal a feed ingredient for pets and fishes. Conversion of RCO into biodiesel may open new vistas for generating wealth from waste besides controlling the major havoc of environmental pollution. A two-step process to convert RCO to good quality Biodiesel was invented. Acid catalysed esterification of FFA followed by base catalysed transesterification of triglycerides was carried out after meticulously standardizing the methanol molar ratio, catalyst concentration, reaction temperature, and reaction time to obtain the maximum biodiesel yield of 97.62% and lowest glycerol yield of 6.96%. RCO biodiesel blend was tested in a CRDI diesel engine. The results revealed that the blending of commercial diesel with 20% RCO biodiesel (B20) lead to less engine wear, a quieter engine and better fuel economy. The better lubricating qualities of RCO B20 prevented over heating of engine, which prolongs the engine life. RCO B20 can reduce the import of crude oil and substantially reduce the engine emissions as proved by significantly lower smoke levels, thus mitigating climatic changes.

***Keywords*—**Biodiesel, Broiler Waste, Engine Testing, Rendered Chicken Oil.

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I. Introduction

WORLD-OVER, the demand for broiler chicken had drastically increased in the last decade. There is more preference for the white chicken meat than the red meat of beef and pork due to increasing health consciousness. Broiler chicken has become the cheapest source of animal protein in many parts of the globe. In Kerala, a small state of India, it is estimated that about 5.3 lakh broilers are slaughtered daily [1]. This results in the production of 350 tones of broiler waste per day. The annual production of broiler waste is to the tune of 15 million kg. The disposal of this much waste is a daunting task. These waste are collected by agents from the chicken stall at the rate of Rs. 4/kg and are now dispose of in uninhabited areas and in water bodies leading to ground and surface water pollution, obnoxious odor and health hazards posed by indiscriminate breeding of microorganism, parasites, house flies and stray dogs. This poses a catastrophic threat to the environment and may result in major health hazards.

Among the different bio-secure and sanitary disposal methods, rendering is an excellent way to recycle a troublesome waste material into a good feed ingredient [2]. The end products are carcass meal and rendered chicken oil. Carcass meal can be used as pet and fish feed ingredient and bio-fertilizer [2]. However, the rendered chicken oil which has high free fatty acid content does not have much commercial value at present. Conversion of rendered chicken oil into biodiesel may open new vistas for generating wealth from waste besides controlling the major havoc of environmental pollution. Therefore, this study was carried out to standardize and optimize the techniques for the conversion of rendered chicken oil into biodiesel.

John Abraham*, Francis Xavier, Deepak Mathew are with School of Bio Energy and Farm Waste Management, Kerala Veterinary and Animal Sciences University, Pookode-673576, Kerala, India (Phone: +91-9447617194; fax:04936-256909; e-mail:johnabe21@gmail.com).

Ramesh Saravana Kumar is with the Veterinary College and Research Institute, Namakkal-637002, Tamil Nadu, India (w-mail: lpmramesh1@yahoo.com).

II. Material and Methods

A. Raw Materials

The broiler waste were collected from chicken stalls and stored in deep freezer at -20°C till sufficient quantity was available for rendering.

B. Dry Batch Rendering

The batch dry rendering process consisted of the following processes; pre-breaking, charging the cooker, cooking, sterilization, drying, centrifuging and milling. The dry rendering machinery (Premium-800) manufactured by M/S Precision Products Private, Limited, India) comprised of pre-breaker, a travelling electric hoist, horizontal steam jacketed cooker (Dry Melter) of 800 litre capacity, equipped with a set of agitators, percolating tank, fat balance tank, centrifugal turbine fat extractor and milling unit.

C. Solvent Extraction of Chicken Oil from Greaves

To maximize the yield, of chicken oil, a pilot study was carried out in a simple lab scale solvent extraction unit. Hexane at a fat-to-solvent ratio of 1:10 (w/v) was used according to the procedure described by [3]. The mixture was stirred for 2 h and the extraction procedure was repeated three times to ensure that the oil was extracted completely. After extracting the fat, the solvent was recovered using the distillation apparatus.

D. Biodiesel Production from Rendered Chicken Oil

The conversion of rendered chicken oil having high Free Fatty Acids (FFA) to biodiesel was tried using a two-step reaction. This process involved the acid catalysed esterification of the FFA portion of chicken fat followed by the base catalysed transesterification of the triglyceride portion. Both these reactions were carried out separately in a reactor. A laboratory scale biodiesel reactor was developed and used for biodiesel production from RCO.

E. Laboratory Scale Biodiesel Reactor

The reactor consists of a three necked 1000 mL flat bottom flask on which was attached a reflux condense, stirrer and thermometer (Fig. 1). The temperature of the flask was

accurately controlled by a digital temperature controlled water bath. The chemicals used were procured from Merk and a separating funnel was used to separate the final product.



Fig. 1 Laboratory scale biodiesel reactor

F. First Step: Acid Catalysed Pre-Treatment

It is known that sulphuric acid is an efficient catalyst for the esterification of FFA [4], [5]. Therefore, sulphuric acid was chosen as the catalyst.

In order to optimize the minimum amount of methanol, sulphuric acid, reaction temperature and reaction time, the following variations of the process variables were carried out thrice, selecting and standardizing the values which gave minimum values of FFA and then standardizing the next variable, until the best combination for converting FFA to usable esters was determined.

TABLE I
EXPERIMENTAL CONDITIONS FOR ACID ESTERIFICATION

Methanol Molar Ratio	Catalyst Concentration of FFA	Reaction Temperature	Reaction Time
10 : 1	0 %	30 °C	30 min
20 : 1	5 %	40 °C	60 min
30 : 1	10%	50 °C	90 min
40 : 1	15%	60 °C	120 min
30 : 1	20%	60 °C	60 min

TABLE II
EXPERIMENTAL CONDITIONS FOR ALKALINE TRANSESTERIFICATION

Methanol Molar Ratio	Catalyst Concentration of FFA	Reaction Temperature	Reaction Time
3 : 1	0.25 %	30 °C	30 min
6 : 1	0.5 %	40 °C	60 min
9 : 1	1.0%	50 °C	90 min
12 : 1	1.5%	60 °C	120 min
6 : 1	0.5%	65 °C	60 min

G. Second Step: Base Catalyzed Transesterification

After the FFA in the RCO was reduced to less than one per cent, the pre-treated oil was converted to biodiesel by alkaline transesterification. Transesterification involves stripping the glycerine from fatty acids with the aid of an alkaline catalyst and replacing it with an alcohol usually methanol to produce Fatty Acid Methyl Ester (FAME). Sodium hydroxide (NaOH) was used as the catalyst in the alkaline transesterification based on previous works of [4]-[6]

Optimal transesterification conditions that produced maximum biodiesel yield was obtained by varying each process variables as stated below and the best combination that resulted in maximum biodiesel yield was determined.

H. Fuel Properties of Biodiesel

The fuel properties (Kinematic viscosity, flash point, fire point, gross calorific value, low temperature fuel properties like could and pour point, carbon residue and Cetane number) were studied and compared with Indian Biodiesel Specification (Bureau of Indian Standards-BIS Specification) and commercially available petro-diesel.

I. Cost of Biodiesel Production

The relative cost of the biodiesel produced was worked out by calculating the rendering cost, processing cost, methanol recovery and the value of the co-product (purified glycerine).

J. Engine Testing

The biodiesel blend; B20 prepared from chicken oil was tested in a four cylinder CRDI engine test rig. The sensors of the engine test rig were integrated to a computer. Performance characteristics were plotted against the percentage load. The performance parameters considered were specific fuel consumption (SFC), total fuel efficiency, brake thermal efficiency, mechanical efficiency, and percentage smoke opacity.

K. Statistical Analysis

All data were analyzed adopting completely randomized design using the software package SPSS.10®. Significant differences between the means were evaluated using Duncan's Multiple Range Test (DMRT) [7]. For optimization of acid and alkali catalysed reaction, a predictive model was obtained and the corresponding coefficients were calculated from the experimental responses through multiple regression analysis using standardized data.

III. RESULTS AND DISCUSSION

A. Dry Batch Rendering

The dry batch rendering regimen of cooking the broiler wastes at 100°C for 20 min followed by sterilizing at 120°C and 2 kg/cm^2 pressure for 20 min, followed by drying at 100°C for 1 h gave the maximum fat recovery.

B. Solvent Extraction of Chicken Oil from Greaves

The overall oil recovery from greaves by solvent extraction method was 96.10 ± 0.14% and the overall solvent recovery was 88.98 ± 0.32%. Solvent extraction method can extract 1.09 kg of oil from the 'greaves' obtained by rendering 7.5 kg of broiler waste. The recovery of 88.98 ± 0.32% of solvent by lab scale model suggests that the recurring expenditure will be very less and the plant is one time investment. McRae et al. [8] had reported that commercial models have up to 97% solvent recovery.

C. Yield of Carcass Meal

The average yield of sterilized poultry carcass meal was 35% of the weight of broiler waste loaded into the cooker. The sterilized carcass meal was used as a feed ingredient with

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61.96 ± 0.60% crude protein and 12.44 ± 0.58% total ash and was sold at the rate of Rs. 30/kg.

D. Biodiesel Production from Rendered Chicken Oil

The results of the FFA values of RCO, 6.46 ± 0.73 to 9.14 ± 0.22 revealed that traditional alkali or base catalysed transesterification cannot be used for the conversion of RCO into biodiesel as the high concentration of FFA gets saponified into soap. Thus, a multiple step process, i.e. acid catalysed esterification of FFA as pre-treatment step followed by the base catalysed transesterification of triglycerides was tried.

E. First Step: Acid Catalysed Pre-Treatment Reaction

The effect of methanol molar ratio when varied from 10:1 to 40:1, the effect of catalyst (sulphuric acid) concentration when varied from 0-20%, the effect of reaction temperature when varied from 30-60°C and the effect of reaction time from 30 to 120 minutes was meticulously researched by replicating the experiments three times for each combination and finding out and standardising the least value for FFA. Acid catalysed esterification of FFA with 30:1 methanol molar ratio, 10% H_2SO4 concentration at 60°C for a reaction period for 120 minutes, could significantly ($p < 0.01$) reduce the FFA value of RCO to a minimum value of 0.70%. Further to study the influence of the combined variables of acid esterification to minimize FFA per cent in RCO, the data were subjected to multiple regression analysis. The model showed a good fit with R^2 value of 0.98.

F. Second Step: Base Catalysed Transesterification

To optimize the conversion of pre-treated oil to biodiesel by transesterification reaction, the reactions were meticulously carried out by varying the methanol molar ratio from 3:1 to 12:1, NaOH concentration from 0.25 to 1.5%, reaction temperature from 30 to 65°C and reaction time from 30 to 120 min. Each reaction was carried out three times finding out and standardizing the values which gave the maximum yield of biodiesel.

The base catalysed transesterification of triglycerides with methanol molar ratio of 6:1, NaOH catalyst 0.5% to triglycerides at 60°C for 90 minutes reaction period produced the maximum biodiesel yield of 97.62% and lowest glycerol yield of 6.96%. The observed total glycerol content of biodiesels was 0.09%. There was no free glycerol in the RCO biodiesel and the methyl ester conversion calculated based on the total glycerol in RCO and in biodiesel was 99.35%. Multiple regression analysis carried out to analyze the combined influence of the reaction variables for obtaining the maximum yield of biodiesel showed a good fit with R^2 value of 0.98.

G. Fuel Properties of Biodiesel

The fuel properties of B100 (100% biodiesel) and B20 (20% biodiesel and 80% diesel), compared with Indian Biodiesel Specification (BIS Specification) and commercially available petro-diesel is presented in Table III.

The kinematic viscosity of RCO biodiesel at 40°C was 5.83 ± 0.05 cST for B100 and that of B20 was 4.74 ± 0.03 cST, against the low viscosity of 4.43 ± 0.04 cST of commercial diesel. The flash point of B100, B20, and B00 were 172.16 ± 0.16, 52.5 ± 0.28 and 50.26 ± 0.37°C. The mean flash point of RCO which was 195.17°C was reduced to 172.16°C in biodiesel (B100) by the process of transesterification. The fire point of B100, B20 and B00 were 183°C, 65.56 ± 0.06°C and 60°C respectively. The mean fire point of RCO (208.32°C) was reduced to 183°C in the corresponding biodiesel by the process of transesterification. The gross calorific value of B100 was 38.71 ± 0.10 MJ/kg, B20 was 39.46 ± 0.20 MJ/kg and that of B00 was 42.42 ± 0.12 MJ/kg. The cloud point of B100 was 5.3 ± 0.05°C and that of B20 was -0.9 °C. The pour point of B100 was 1.8 ± 0.05°C and that of B20 was -15 ± 0.16°C. B100 had a mass carbon residue of 0.13 ± 0.03%, B20 0.21 ± 0.003% and the same for commercial diesel was 0.24 ± 0.03%. The commercial diesel had more carbon residue of 0.24%. Compared to commercial diesel (B00) which had a Cetane number of 54.4, biodiesel blend B20 had a Cetane number of 64.8 and B100 had a high Cetane number of 72.5. This indicated that B100 would have shorter ignition delay leading to high engine efficiency and subsequently reduced exhaust emissions.

Overall, the biodiesel prepared from RCO had good fuel properties and conformed to the BIS specification for biodiesel. The fuel properties of biodiesel blend B20 was more close to that of commercial diesel except for carbon residue, which revealed that B20 and B100 would produce less smoke compared to commercial diesel.

TABLE III
FUEL PROPERTIES OF BIODIESEL

Fuel properties	B100	BIS specification	B20	B00 (Diesel)
Kinematic viscosity at 40°C (cST)	5.83 ± 0.05	2.5-6.0	4.74 ± 0.03	4.43 ± 0.04
Flash point (°C)	172.16 ± 0.16	120 mini	52.5 ± 0.28	50.26 ± 0.37
Fire point (°C)	183	-	65.56 ± 0.06	60
Ash content (%)	0.23 ± 0.04	-	0.37 ± 0.01	0.21 ± 0.01
Gross calorific value (MJ/kg)	38.71 ± 0.10	-	39.46 ± 0.20	42.42 ± 0.12

H. Cost of Biodiesel Production

Taking into consideration the rendering cost, solvent extraction cost, the processing cost of biodiesel and the yield of co-product glycerine, the cost of RCO biodiesel was worked out to be **Rs. 22.00/L**. Considering the present diesel cost of **Rs. 56.58/L**, cost of RCO biodiesel seems to be reasonable and in sustainable proportions.

I. Engine Testing

In the engine trial, the total fuel consumption and brake specific fuel consumption were low compared to commercial diesel at all tested loads, while mechanical efficiency and brake thermal efficiency were high compared to commercial diesel at all tested loads. At the maximum brake power of 58 kW, the smoke opacity of B20 was 47.14% less than that of diesel. The exhaust gas temperature was lower in the entire range of loads, while using B20.

The blending of commercial diesel with 20% RCO biodiesel leads to less engine wear, a quieter engine, and better fuel economy. The better lubricating qualities of RCO-B20 prevented over heating of engine, which prolongs the engine life. The blending of biodiesel at 20% to commercial diesel can reduce the import of costly crude oil and simultaneously, substantially reduce the engine emissions as proved by significantly lower smoke levels (47.14%) compared to that of diesel in a CRDI engine.

IV. Conclusion

Utilization of broiler slaughter waste by dry rendering process produced RCO a cheap raw material. Its low operating cost in biodiesel production make this study a promising one for possible green technological applications. The rendered chicken oil with high FFA could be converted to good quality biodiesel by two-step process viz. acid catalysed esterification of FFA followed by alkali catalysed transesterification of triglycerides. Chicken oil methyl ester blended with diesel fuel could be used as an alternative fuel in conventional diesel engines without any major modifications and it improves mechanical efficiency, brake thermal efficiency, and decreases smoke emissions by 47.14%, reducing pollution and mitigating climatic changes.

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