

RESEARCH ARTICLE

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Production and statistical optimization of biodiesel from kitchen chimney dump lard

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Abstract

Background: The global upsurge in world energy demand, sharp decline in petrofuels reserves, and greater concerns about the environment has constrained mankind to investigate newer and renewable feedstocks for liquid transportation fuels. Existent bioenergy feedstocks cannot suffice for the petro crude reserves, new feedstock for the same will serve as an incremental step for addressing the long recognized problem of energy supply and simultaneously also support further research endeavors related to green chemistry, feed stock biology and bio-energy research. In this regard, the present investigation aims to highlight kitchen chimney dump lard (a bio-waste), as a prospective feedstock for biodiesel production.

Results: Statistical implication (response surface methodology, RSM) can be helpful in design of experiments for biodiesel production and allied approaches. Biodiesel was produced from KCDL which contains high amount of free fatty acids (acid value 28 mg KOH/gm) by a two stage transesterification process. The biodiesel yield was optimized using RSM for optimal production and the yield was found to be 82% compared to 80% predicted using RSM. The biodiesel was characterized by CHN, GC-MS and FTIR spectroscopy. The fuel properties namely density, viscosity, cloud point, pour point, flash point and calorific value were analyzed to access the quality of the fuel. The results suggest the feasibility of biodiesel production from KCDL.

Conclusion: Production of biodiesel from KCDL is feasible and warrants necessary research.

Keywords: Energy, Feedstock, Kitchen chimney dump lard, RSM, Transesterification, FTIR

Background

Human society is witnessing transition from a petroleum based liquid fuel infrastructure to one based on renewable sources [1]. The continuous depletion of fossil energy sources and concerns over carbon dioxide emissions has further shifted the global trend towards development of new and consistent bio-based resources [2]. The exhaustion of petroleum based fuels is foreseeable and resultant scientific endeavors are on the cards for investigating new renewable energy sources for biofuel production. One of the high priority options for addressing this expedition for the search of new energy sources can be offered by energy derived from biomass. Biomass has the potential to become one of the major global pri-

bio-energy systems are suggested to be significant contributors to futuristic sustainable energy systems and to sustainable development in industrialized as well as in developing nations [3-12].

Scientific exploration and utilization of new bio-energy feedstocks for biofuel production is a fundamental task in fostering bio-energy research and sustainable development. Much emphasis has been laid on identification of suitable biomass feedstocks which can provide high energy output to replace conventional fossil fuel energy sources [13]. The greatest share of biofuel production cost is associated with feedstock, therefore the availability of low cost and good quality feedstock is crucial for large scale commercial use of biofuels [14-16]. The high prices of commodity vegetable oils and animal fats have made exploration of economical alternative non-food feedstocks an important research topic [17]. The production of biofuels especially biodiesel from low cost and inexpensive feedstocks like non-edible oils, animal

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fats, waste frying oils, agro-wastes etc have already gathered the scientific momentum in lieu of concerns for reduction in cost of production and economic compatibility with petro-diesel.

As extensive search operations for new feedstocks continues, even wastes (agro-wastes, municipal wastes, industrial wastes, waste cooking oil etc.) have started hitting the block. Under the aegis of green chemistry, bioenergy research and feedstock biology, energy generation from waste seems to be partially compassionate in addressing issues related to renewable liquid fuels. Moreover with the advancement in biomass conversion technologies the day is not far when a fraction of the international road fuel needs, could potentially be addressed by biofuel production from wastes. For a third world economy like India, biofuel production from waste is attractive not only with regard to energy security, but also in terms of environmental context (waste disposal and management) and economic aspect (revenue generation from subsequent energy recovery). Judicious and optimal use of total energy generation potential from inexpensive feedstocks/bio-wastes could unlock new vistas for abating the long term dilemma of energy supply. In this regard, the present investigation aims to highlight a bio-waste generated from kitchen chimneys, kitchen chimney dumped lard (KCDL), as a prospective feedstock for biodiesel production. Some of the salient features of KCDL towards bioenergy generation are

- 1) It is primarily a kitchen waste, and can be of great value with respect to energy recovery.
- 2) It can be easily accessed from kitchen chimneys of hotels, restaurants, hostels and large cooking facilities”.
- 3) It is renewable as the primary feedstock is a vegetable oil.
- 4) KCDL based biodiesel has a good energy content (36.5 MJ/Kg).
- 5) It has low ash content (0.05%).
- 6) KCDL based biodiesel has good degree of saturation (41.86%) thereby making it more stable.

Increased reliance on wastes (such as KCDL) for energy generation may play an incremental role in slowly reducing mankind's dependence on fossil fuels in coming days. The availability of the KCDL used in the present investigation depend upon numerous factors such as frequency of cooking, types of oils used for cooking, types of food items being cooked (especially deep fried food stuffs) etc. It is formed as a result of frying processes where the vapors of the cooking oil after condensation gets collected in semi solid form in the collecting ducts of a kitchen chimney.

The current work is an endeavor to investigate KCDL as a prospective new and renewable feedstock for biodiesel production and subsequent statistical optimization of biodiesel yield using response surface methodology. The feasibility of transesterification process via two stage transesterification and determination of fuel properties viz. density, viscosity, cloud point, pour point, flash point, and calorific value were further done to access the quality of KCDL based biodiesel.

Results and discussion

The identification of suitable feedstock and subsequent biomass conversion would contribute significantly towards futuristic bio-energy utilities. The graphical representation for the scheme of work done (from feedstock collection to biodiesel production and fuel characterization) has been shown in Figure 1. The feedstock used for this study, KCDL was collected from the kitchen chimney of Nilachal Men's Hostel, Tezpur University, Assam-784028, India (26.7008°N and 92.8303°E). KCDL is primarily a kitchen waste (a bio-waste which is renewable in nature, since the primary feedstock is a vegetable oil) which can be collected from the horizontal collecting ducts present in a kitchen chimney. It is formed as a result of frying processes where the vapors of the cooking oil after condensation gets collected in semi solid form in the collecting ducts of a kitchen chimney. KCDL feedstock (light brown in color and murky odor) had a density of 2.01 gm/cc, average molecular weight of 825.02 and an acid value of 28 mg KOH/gm, but however there may be variability in physical properties of the feedstock which is chiefly governed by product purity and time of exposure of the feedstock to atmospheric oxygen.

Numerous research work have been carried out on biodiesel production from waste oils or animal fats, describing the practicability of making quality biodiesel from these feedstocks thereby identifying the problems with the free fatty acids (FFA) present in these raw materials. The presence of FFA and water in these feedstocks results in soap production in the presence of alkali catalyst. Henceforth, additional steps for water removal and either the FFA or soap from the reaction mixture are required [18]. Special processes are required for transesterification of fat/oils containing significant amount of free fatty acids. Pretreatment processes using strong acid catalyst have been shown to provide good conversion yields and high quality final products [19]. One of the common methods employed to reduce the free fatty acid (FFA) content of a feedstock when present in excess of 1 wt% is a two step process, where acidic pretreatment of the feedstock is first done to lower its FFA content followed by homogenous base catalyst based transesterification to produce biodiesel [20-23]. KCDL feedstock had an exceptionally high acid value of

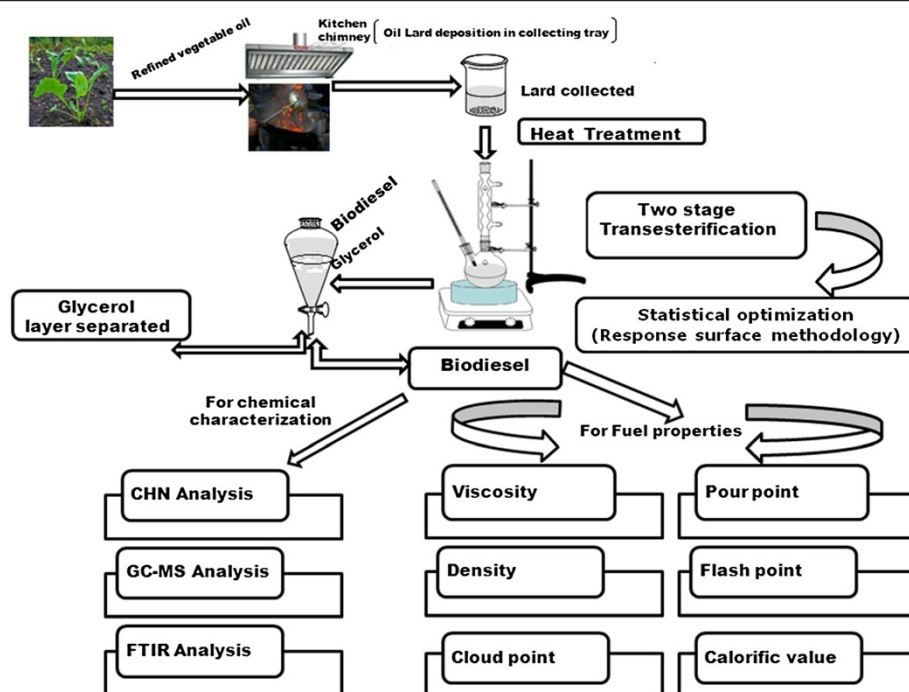


Figure 1 Graphical abstract from feedstock collection to biodiesel production and subsequent characterization.

28 mg KOH/gm and henceforth biodiesel was produced by a two stage transesterification process. The first stage esterification (acidic) was catalyzed by conc. H_2SO_4 whereas the second stage (basic) by NaOH.

The elemental content of carbon, hydrogen, nitrogen and oxygen in the biodiesel sample were 59.98, 9.51, 0.69 and 29.82 respectively. The lower content of nitrogen in the biodiesel sample is important especially with regard to environmental protection. The major difference between biofuels and petroleum feedstocks is oxygen content. The oxygen content in biofuels ranges from 10 to 45% while petroleum has essentially none, making the chemical properties of biofuels quite different from those of petrofuels [24]. The Gross calorific value (GCV) and Net calorific value (NCV) for KCDL biodiesel was 36.5 MJ/Kg and 34.40 MJ/Kg respectively, which is slightly lower than that reported by Demirbas for other biodiesels (39 to 41 MJ/Kg) [24]. The GCV for KCDL biodiesel was less than that reported by Sharon *et al.*, for methyl esters (biodiesel) derived from veg fried oil and non-veg fried oil viz., 42.59 MJ/Kg and 42.38 MJ/kg respectively [25].

The present investigation included optimization of biodiesel yield by RSM. Biodiesel yield (wt %) relative to the weight of KCDL was estimated. The RSM experiment was not extended for the pre-treatment step (acid catalyzed esterification). The statistical optimization

employed using Box-Behnken [26] design showing the level of four independent variables includes Methanol (X_1), NaOH (X_2), Temperature (X_3) and Time (X_4) were further investigated at three different levels as listed in Table 1.). Table 1 showed the design matrix of the variables with the experimental results of the biodiesel yield. The experimental results were displayed in the form of three-dimensional response surface plots and contour plots.

Figure 2 described the contour plots which explore the relationship between the variables used in the present investigation i.e. methanol, NaOH, temp, and time for biodiesel yield. The plot displays the three dimensional relationship in the form of a two dimensional plot. In Figure 2 contours levels viz. methanol, NaOH, temperature and time which influence the biodiesel yield is represented.

The salient findings of RSM methodology were

- gradual increase in biodiesel yield with high level of NaOH and temperature (Figure 3A).
- increase in biodiesel yield with increase in the level of methanol and time (Figure 3B).
- increase in yield with increment in the level of NaOH and decrease in yield with increment in time (Figure 3C).
- decrease in biodiesel yield with increase in the level of methanol and NaOH (Figure 3D).

Table 1 Box–Behnken experimental design, representing the response of biodiesel yield as influenced by methanol, NaOH, temperature and time

Run order	Methanol	NaOH	Temperature	Time	Yield	Predicted yield
1	0	−1	0	1	80	81.179
2	0	1	0	−1	75	75.647
3	0	0	0	0	83	84.202
4	0	0	−1	−1	84	83.904
5	1	1	0	0	81	81.772
6	0	0	−1	1	85	86.571
7	1	0	0	−1	80	78.821
8	−1	1	0	0	75	73.396
9	0	1	0	1	79	79.314
10	−1	0	−1	0	84	85.648
11	1	−1	0	0	84	81.733
12	0	0	0	0	82	84.202
13	0	−1	1	0	95	94.083
14	−1	0	1	0	87	87.424
15	0	1	−1	0	84	83.355
16	0	−1	−1	0	95	89.316
17	−1	0	0	−1	89	89.349
18	1	0	−1	0	78	81.206
19	0	1	1	0	80	79.313
20	0	0	0	0	84	84.202
21	1	0	1	0	82	83.982
22	1	0	0	1	85	82.487
23	0	0	1	1	79	79.433
24	0	−1	0	−1	93	94.513
25	−1	−1	0	0	94	94.166
26	−1	0	0	1	77	76.016
27	0	0	1	−1	93	91.766

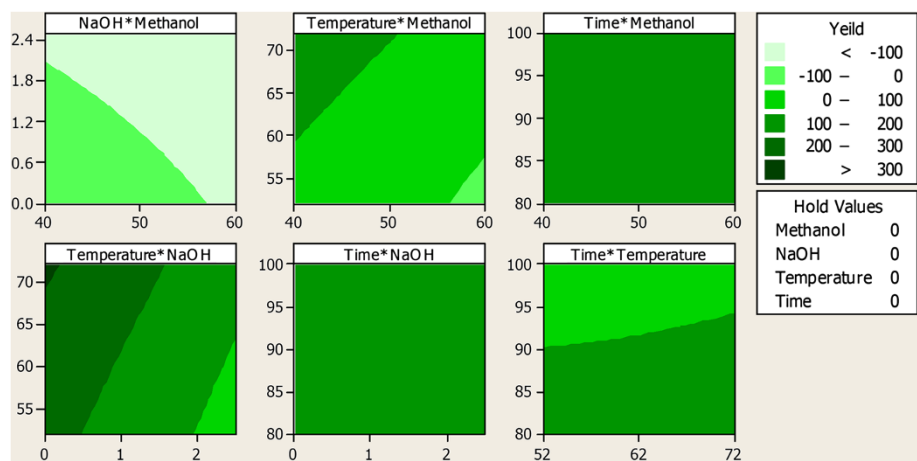


Figure 2 Contour plots of biodiesel yield as influenced by methanol, NaOH, temperature and time. The darker green contour region represents higher biodiesel yield (>300) while the lighter green colour represents lower biodiesel yield (<−100).

For predicting the optimal point, a second order polynomial function was fitted to the experimental results of biodiesel yield:

$$\begin{aligned} Y \text{ activity} = & 113.430 + 3.053X_1 + 55.130X_2 + 0.934X_3 \\ & + 1.694X_4 + 0.520X_1X_2 + 0.007X_1X_3 \\ & + 0.043X_1X_4 + 0.220X_2X_3 + 0.425X_2X_4 \\ & + 0.038X_3X_4 \end{aligned} \quad (1)$$

Where, X_1 , X_2 , X_3 and X_4 are the Methanol, NaOH, temperature and time respectively.

The regression model (eq. 1) fits the experimental data well with a high R^2 (coefficient of determination) value of 90.81%. The value of R^2 thus obtained suggests a high degree of correlation between the experimental and the predicted values. The closer the value of R^2 to 1.00, the stronger is the correlation between the measured and the predicted values. In the present investigation the calculated coefficient of determination value indicates that the model could explain 90.81% of the variability in the response.

To find out the optimum condition and to confirm the validity and accuracy of the model, an experiment was carried out under basal and predicted optimal conditions where biodiesel yield was monitored compared to the calculated data from the model. The estimated biodiesel yield was 82% compared to 80% of the predicted value from the polynomial model. Thus, it points out the accuracy of the model with more than 97.56 % which is an evidence for the model validation. However, this variance of biodiesel yield might be because of slight variation in the experimental conditions. In short, the statistical optimization was applied to find out the optimal biodiesel yield and found to be an effective statistical technique for higher biodiesel yield.

The FTIR spectra of the feedstock and biodiesel, shown in Figure 4, are quiet similar since both have almost the same chemical groups. The IR spectra of KCDL biodiesel shows a C=O stretching band of methyl esters at 1748 cm^{-1} and C-O bands at 1130 and 1196 cm^{-1} [27]. The aliphatic hydrogen at 2928 cm^{-1} and 2856 cm^{-1} are indicative that the main components of the biodiesel sample are long carbon chains [28]. C-H deformations between $1500\text{--}1300 \text{ cm}^{-1}$ further verify the presence of long carbon chains [29].

The identification of FAME's (shown in Table 2) by GC-MS analysis was performed through comparison of their mass spectra with those in NIST library. The saturated and unsaturated FAME in the biodiesel sample were 41.86 and 58.14% respectively. A high degree of saturation is likely to make the fuel more stable. The average molecular weight of the KCDL methyl esters was 276.34.

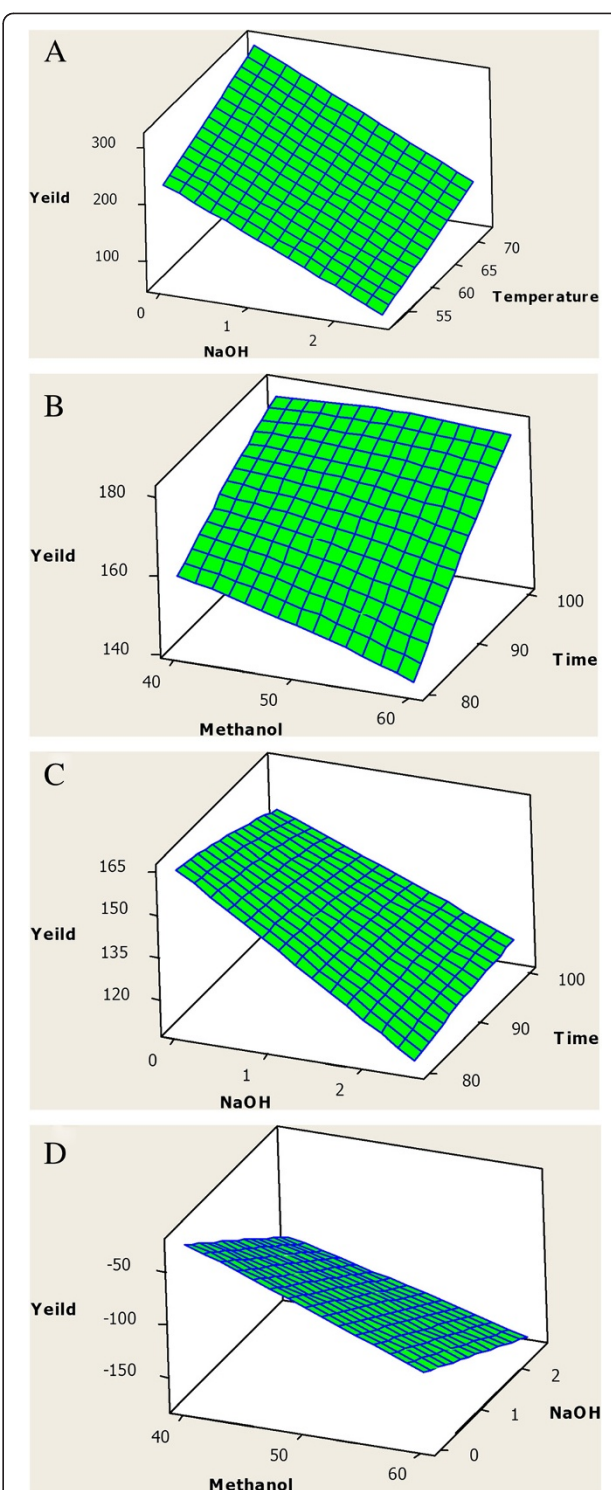


Figure 3 Response surface showing the surface plot of (3A) Yield vs Temperature, NaOH (3B) Yield vs Time, Methanol (3C) Yield vs Time, NaOH and (3D) Yield vs NaOH, Methanol.

There exists variability in the chemical composition of different biodiesel feedstocks, and henceforth variations in the fuel properties of biodiesel produced from different

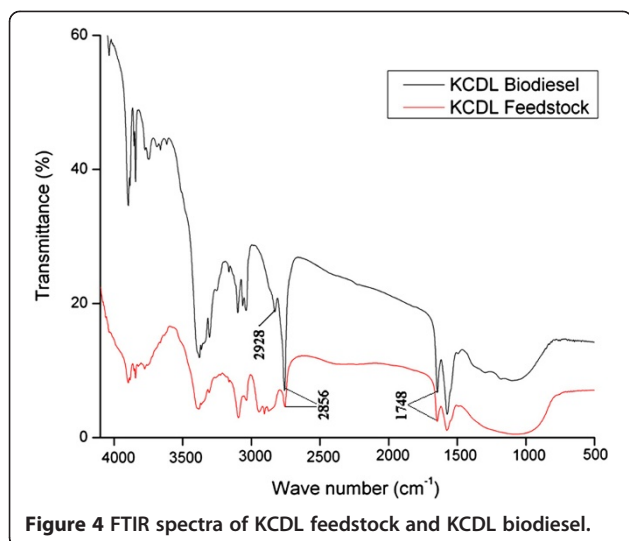


Figure 4 FTIR spectra of KCDL feedstock and KCDL biodiesel.

feedstocks is imperative. The fuel characterization of KCDL based biodiesel has been presented in Table 3. The high viscosity (8.7 mm²/s) of KCDL based biodiesel in contrast to others viz., waste cooking oil (4.89 @40°C, mm²/s) [30], methyl esters of veg fried oil (5.11 @40°C, mm²/s) and methyl esters of non-veg fried oil (5.81 @40°C, mm²/s) [25] is the major bottleneck for practical usability of the fuel in diesel engine. However, use of biosurfactants (being environmentally benign in nature in contrast to chemical surfactants) for reducing the viscosity of the sample fuel is in progress and will be reported in subsequent publications. Also, for our work it is also very important to realize the blending of biodiesel with petrodiesel for determining the optimum blending composition and subsequent blend characterization.

Conclusion

Global trends pertaining to energy crisis, energy security and environmental deterioration will significantly contribute towards the investigation of newer bio-based feedstocks for biofuel production. Several studies have been carried out regarding the production of biodiesel from edible and non-edible sources describing the feasibility of making biodiesel from these feedstocks. The

Table 2 FAME's identifiable by GC-MS analysis

SN	Fatty acid methyl ester (FAME)	Molecular formula	Wt (%)
1	Nonanedioic acid, dimethyl ester	C ₁₁ H ₂₀ O ₄	5.68
2	Tetradecanoic acid, 10,13-dimethyl-, methyl ester	C ₁₇ H ₃₄ O ₂	34.95
3	9-octadecenoic acid, methyl ester, (E)-	C ₁₉ H ₃₆ O ₂	39.92
4	9-hexadecenoic acid, methyl ester, (Z)-	C ₁₇ H ₃₂ O ₂	18.82
5	Heptacosanoic acid, 25-methyl, methyl ester	C ₂₉ H ₅₈ O ₂	1.21

Note: Saturated =41.86% and unsaturated =58.14%.

present investigation was carried out to evaluate KCDL as a potential feedstock for biodiesel production. The study clearly suggests that the production of biodiesel from KCDL feedstock is feasible. Moreover, the application of RSM is quite helpful in design of experiments for optimal biodiesel production and allied approaches. The fuel under investigation may also be blended with petrodiesel for determining the fuel characteristics of the blends and thereby determining the optimum blending composition (a part of planned future research activity). In addition, the study also requires greater research capacities (viscosity reduction, oxidative stability etc.) to enable a better comprehensive understanding of biodiesel production from KCDL. On a global scale tons of raw feedstock (deposited lard in kitchen chimneys) may be collected annually and henceforth true techno-economic evaluation of the process is necessary in a pilot scale. Conclusively, research endeavors in newer feedstocks for biofuel production will serve as an incremental step in further efforts related to bio-energy.

Experimental

Determination of acid value

The acid value of the sample was determined by titrating it against KOH using phenolphthalein as an indicator. The calculations were done using the following formula [31]

$$\text{Acid value (mg KOH/gm)} = \text{Titre value} \times \text{Normality of KOH} \times \frac{56.1}{\text{Weight of the sample (gm)}}$$

Where, the factor 56.1 is taken from Equivalent weight of KOH since 1ml 1 N KOH contains 56.1 mg weight of KOH.

Transesterification

A two stage transesterification process was used for production of biodiesel from KCDL. In the first stage, concentrated H₂SO₄ (97% purity) was used as an acid catalyst to convert high FFAs to esters and in the second stage NaOH was used as an alkali catalyst to convert triglycerides to biodiesel. The standard biodiesel reaction mixture consisted of KCDL, methanol and appropriate concentration of catalysts (acid and basic).

Heat treatment of feedstock

Prior to acidic esterification the KCDL feedstock was heated at 120°C for 30 min. This step is required to melt all the solid fat present in the feedstock.

Two stage transesterification and statistical optimization

The sample from the previous step was taken and allowed to cool to a temperature of 50°C and required

Table 3 Biodiesel properties

Properties	KCDL Biodiesel	Standard test method used
Density (40°C, g/cm ³)	0.9	ASTM D 5002
Viscosity (mm ² /s, cSt at 40°C)	8.7	ASTM D 445
Cloud point (°C)	8	ASTM D 2500
Pour point (°C)	11	ASTM D 97
Gross calorific value (MJ/kg)	36.5	Adiabatic Bomb Calorimeter
Net calorific value (MJ/kg)	34.40	Equation for calculation of NCV [36]
Flash point (°C)	123	ASTM D 93
Ash content (Wt %)	0.05	ASTM D 874

Note: Determination of cetane number was not a part of this study.

amount of methanol (60% by vol, 99% purity) was added. Following this, H₂SO₄ (3% v/v, 97% purity) was added to the mixture and the reaction was commenced at 50°C with 600 rpm for 60 min. Once completed the reaction mixture was placed in a separating funnel and left to stay overnight. The upper layer being a mixture of unreacted triglycerides, unreacted methanol and esters was separated from the lower layer. This layer was washed thrice with warm water (~60°C) to remove the unreacted catalyst and methanol. Finally the product (esterified) was heated at 115°C for 20 min to ensure moisture removal.

The second phase of the two stage transesterification process (alkali catalyzation) was optimized using response surface methodology (RSM). RSM explores the relationships between the explanatory variables with the response variables. Its main idea is to obtain an optimal response using a sequence of designed experiments [32,33]. In the present investigation, Box–Behnken design [27] experiment for RSM was employed for four independent variables viz. Methanol (X_1), NaOH (X_2), Temperature (X_3) and Time (X_4) for the optimal biodiesel yield during the second stage transesterification step. The ranges of the four variables studied is shown in Table 4 and the factors of highest confidence levels were represented in three levels, coded -1 for low, 0 for middle and +1 for high.

The actual design matrix of 27 trials of experiments is given in Table 1. The actual experiments were

performed and the values are presented as yield in Table 1. The behaviour of the system can be explained by the quadratic equation

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{34}X_3X_4 \quad (2)$$

where, Y is the predicted response, β_0 model constant; X_1 , X_2 , X_3 and X_4 independent variables; β_1 , β_2 , β_3 and β_4 are linear coefficients; β_{12} , β_{13} , β_{14} and β_{23} are cross product coefficients and β_{11} , β_{22} and β_{33} are the quadratic coefficients.

Further, the experimental data obtained were interpreted using Minitab 15 statistical software [34] to estimate the response of dependent variable. The quality of fitness of the polynomial model equation was expressed by the coefficient of determination (R^2).

In the present optimization the optimized values were 40.08 for methanol (X_1), 1.86 for NaOH (X_2), 52 for temperature (X_3) and 100 for time (X_4) from the response surface optimizer.

As per the optimization response, 1.86% NaOH (by wt) was dissolved in 40% (by vol) methanol (99% purity) to prepare the alkali catalyst-methanol mixture. This mixture was prepared freshly to maintain catalytic activity and prevent moisture absorbance. Following this the alkali catalyst-methanol mixture was added to the esterified product and alkali transesterification was commenced at 52°C with 600rpm for 100 min. The reaction mixture was then placed in a separating funnel and left to stay overnight. Two distinct layers were formed, the upper layer (biodiesel) and the lower layer (glycerol). The two layers were gravity separated with glycerol simply drained off from the bottom of the separating funnel. The separated biodiesel layer was subjected to the same washing and heat treatment as of the acidic esterification stage. Biodiesel yield (wt %) relative to the weight of KCDL was estimated.

FTIR analysis

The IR spectrum of the samples (KCDL feedstock and biodiesel) was recorded in a (Perkin Elmer, Spectrum100) spectrometer at room temperature (26±2°C) in the mid IR range 4000–400 cm⁻¹.

Determination of Gross calorific value (GCV)

The Gross calorific value of the biodiesel was determined using an automatic adiabatic bomb calorimeter (Changsha Kaiyuan Instruments Co., 5E-1AC/ML). The sample (1ml biodiesel) was oxidized by combustion in an adiabatic bomb containing 3.1 Mpsi oxygen under pressure. The assays were carried out in triplicates and the mean values are reported [35].

Table 4 The levels of variables chosen for the Box–Behnken optimization experiment for biodiesel yield

Variables	Variable code	-1	0	+1
Methanol	X_1	40	50	60
NaOH	X_2	.5	1.5	2.5
Temperature	X_3	52	62	72
Time	X_4	80	90	100

Determination of Net calorific value (NCV)

The equation for calculation of NCV is as follows [36]

$$\text{NCV} = \text{GCV} \times \left(1 - \frac{w}{100}\right) - 2.444 \times \left(\frac{w}{100}\right) - 2.444 \times \left(\frac{H}{100}\right) \times 8.936 \times \left(1 - \frac{w}{100}\right); \left[\frac{\text{MJ}}{\text{Kg}}, w.b.\right]$$

Where 2.444=Enthalpy difference between gaseous and liquid water at 25°C.

$$8.936 = \frac{M_{H_2O}}{M_{H_2}}; \text{i.e. the molecular mass relation between } H_2O \text{ and } H_2$$

Where,

NCV= Net calorific value

GCV= Gross calorific value

h= Concentration of hydrogen in weight%

w= Moisture content of the fuel in weight%

Determination of fatty acid profile

The fatty acid methyl ester (FAME) profile (shown in Figure 5) was analyzed by a Perkin Elmer Clarus 600 gas chromatograph (GC) coupled with a Perkin Elmer Clarus 600C mass spectrometer (MS) equipped with Elite 5MS capillary column (30 m × 0.25 mm × 0.25 μm).

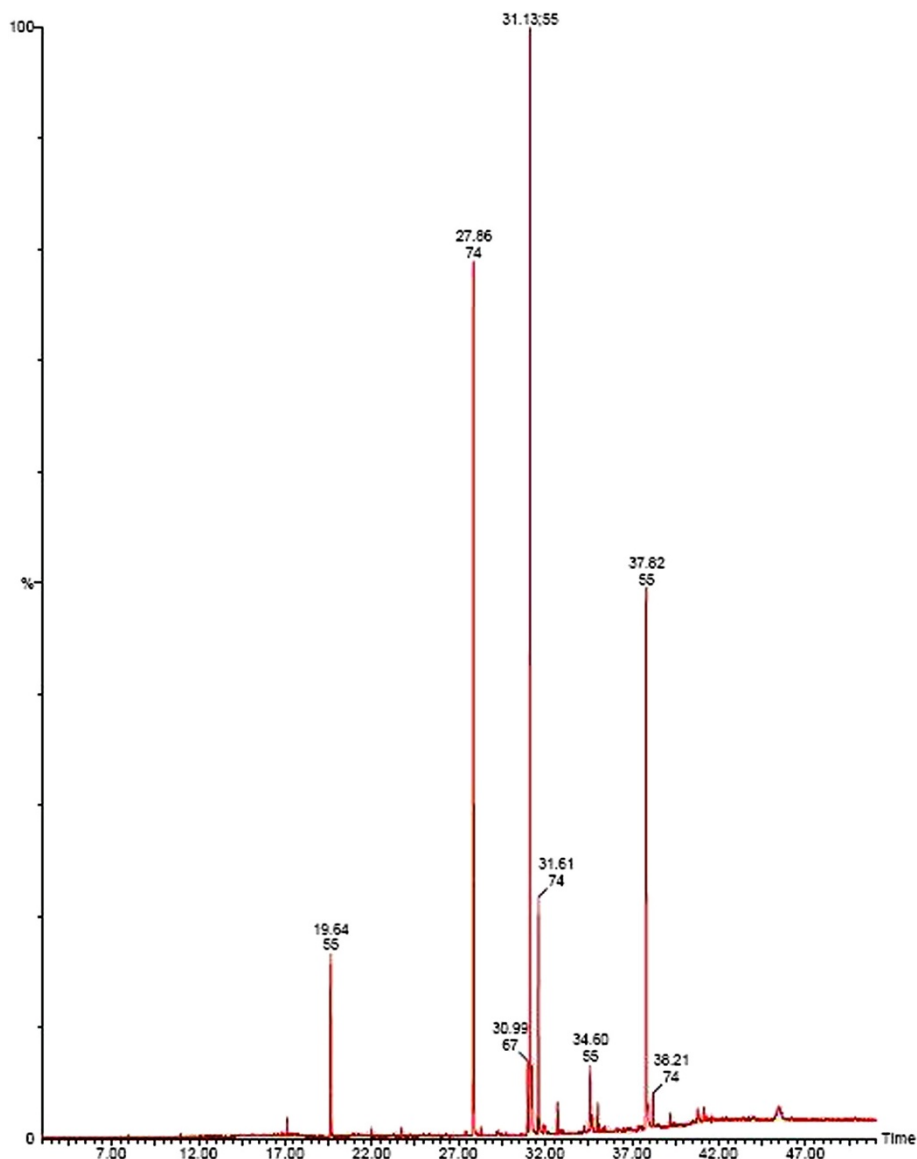


Figure 5 GCMS profile of KCDL Biodiesel.

The oven temperature was programmed from 85°C (5 min) to 265°C at a rate of 5°C/min and finally held at 265°C for 10 min. Helium was used as the carrier gas with a flow rate of 1 ml/min. The MS was operated in electron ionization mode at 70eV. The interface temperature was 265°C and the mass range was 15–650 m/z. The identification of fatty acids was performed, comparing the obtained mass spectra with NIST library.

Analysis of KCDL based biodiesel

The properties of biodiesel viz. density, viscosity, cloud point, pour point, flash point and calorific value were determined using standard methods and the results are presented in Table 3. The carbon, nitrogen and hydrogen content of the biodiesel sample were determined in a Perkin Elmer, 2400 Series-II analyzer. The percentage of oxygen was calculated by difference.

Abbreviations

KCDL: Kitchen chimney dump lard; RSM: Response surface methodology; CHN analyzer: Carbon hydrogen and nitrogen analyzer; GC-MS: Gas chromatography-mass spectra; FTIR: Fourier transform infra red spectroscopy; FFA: Free fatty acids; GCV: Gross calorific value; NCV: Net calorific value; IR: Infra red; FAME: Fatty acid methyl ester.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MMP, TB carried out FTIR analysis, GCMS and fuel characterization. SPS carried out the statistical optimization. ND carried out the CHN analysis. MMP, SPS, PP and BKK conceived of the study, and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

Acknowledgement

MMP thanks Dept. of Science & Technology, New Delhi for providing research grant in the form of DST-INSPIRE fellowship. SPS thanks Dr. T. Madhan Mohan, Adviser, Dept. of Biotechnology, New Delhi, India for promoting Bioinformatics in North-East India. MMP & SPS thank Vice-Chancellor, Tezpur University, Assam for encouragement.

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Received: 6 February 2013 Accepted: 22 July 2013

Published: 6 August 2013

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doi:10.1186/2043-7129-1-12

Cite this article as: Phukan et al.: Production and statistical optimization of biodiesel from kitchen chimney dump lard. *Sustainable Chemical Processes* 2013 1:12.

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