RESEARCH ARTICLE OPEN ACCESS

Biodiesel Production from Waste Cooking Oil & Its Evaluation in Compression Ignition Engine Using RSM

Jashan Deep Singh[a] , Beant Singh[b]
[a] Research Scholar, PCET, Lalru Mandi
[b] Department of Mechanical Engineering, PCET, Lalru Mandi

ABSTRACT
Lack of energy, deterioration of the environment and hunger,these are the three problems the humans are facing in todays era. There is an exponential rise in the demand is arrising for petroleum based energy. This has been followed by problem of depleting conventional petroleum fuels and a hike in price of these fuels, almost on a regular basis. Moreover, these green house emissions are results of petroleum fuels and other forms of pollution in the environment. The rise in the price of the fuel has also been alarming for us to find alternate energy resource.The vegetable oils has proved to be a promising source to obtain fuels for IC engines. Like, biodiesel is biodegradable, non- toxic and renewable fuel. It is obtained from vegetable oils, animal fats and waste cooking oil by transesterification with alcohols. The high cost of raw materials and lack of modern technology has led to the commercialization which can optimize the biodiesel yield. A modified engine can lead to better engine performance along with lesser specific fuel consumption. In this thesis, Response Surface Methodology (RSM) has been used which has focused on the optimization of biodiesel production, engine performance and exhaust emission parameters. There is abundant availability of Waste cooking oil in India which is non- edible. Biodiesel performance testing is done using C.I engine.Biodiesel has been prepared using waste cooking oil which is prepared by mechanical stirring method and compared with diesel. An experimental investigation to evaluate the performance, emission and combustion characteristics of a diesel engine. The optimization of performance and exhaust emission parameters of diesel engine which is run using waste cooking oil biodiesel. The studies were performed on single cylinder, four-stroke, water cooed, direct injection kirloskar diesel engine. The performance parameters like brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and unburnt hydrocarbons (HC), carbon monoxide (CO), nitrous oxide (NO_x) and smoke have been tested upon by the biodiesel and are optimized using Response Surface Methodology. A.V.L smoke meter has been used to check smoke capacity. The performance parameters were identified to be very close to mineral diesel. The emission like carbon monoxide, nitric oxide and hydrocarbons were found to be lesser in quantity than commercial diesel.

Keywords: Waste Cooking oil based biodiesel, Performance and emission characteristics, Response Surface Methodology, Central Composite Design.

I. Introduction

Hunger, lack of energy and the deterioration of the environment these are the particular problems faced by the humans. There has been an exponential rise in the demand of petroleum based energy. The fuels which are derived from petroleum are high in demand as compared to any of other energy fuels. The depletion of fossil fuels has resulted into a dire need to search for an alternative source of fuel to fulfill the demands of the world. The concern has increased for environmental of non-renewable natural resources. Ofence a range has been developed for replacing traditional fossil fuels and it has received a large interest in the last few decades. A research has been directed towards the alternative fuels due to increasing in the petrol prices and limitation of fossil fuel. Alternative diesel fuels are made from natural, renewable sources such as vegetable oil and fats **Lokesh et al. [1]**. The oil-bearing crops like soybean, palm, sunflower, safflower, cottonseed, rapeseed, pongame, castor bean, and peanut oils are used as potential alternative fuels for diesel engines and there are more than 350 of such crops. Vegetable oils are promising feed stocks for biodiesel production since they are renewable in nature, can be produced on a large scale, and environmental friendly **Sims et al.[2]**. Vegetable oils are of both edible and non-edible oils because of higher production of edible oil feed stock, 95% of biodiesel production comes from it and its properties are suitable for diesel fuel substitute.However, it may cause some problems such as the competition with the edible oil market, which increases both the cost of edible oils and biodiesel **Demirbaset et al.[3]**. The researchers have found a parallel path in non-edible oils which are unsuitable for human consumption because some toxic components are present in the oil. They are not suitable for food crops as well as cultivation cost is much lower as without intensive care, the yield is much higher. Animal fats contain higher levels of saturated fatty acids therefore they are solid at room temperature and that may cause problems in the production process. Its cost is also higher than vegetable oil **Lokesh et al. [1]**.

II. Materials and Methodology

Single cylinder, four strokes, natural aspirated, and water cooled direct injection diesel engine which is connected to the eddy current dynamometer, these all have constituted the experimental set up. Necessary instrument has been used for measurement of crank angle and combustion pressure. For measuring interfacing temperature, air flow, fuel flow and load measurement many sansors have been used. The set up consist of two fuel tanks, one is for biodiesel & other is for diesel, fuel measuring unit, standalone panel box consisting of air box fabricated. Use of rota meter for cooling water measurement and Calorimeter for water flow measurement has been made. Manometer was use to measure intake air mass flow rate. Fuel consumption meter has been used to measure fuel consumption rate. The set up is used for the measurement of engine and performance parameters like brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE). Many harmful gases like carbon-monoxide(CO), unburnt hydrocarbons(HC), nitrogen oxides (NO_x) and smoke are produced by diesel engine which are harmful for environment and results in greenhouse effect, air pollution and acid rain. There is also the measurement of exhaust with this engine Horiba Analyzer is used to measure exhaust emission of HC, Flue Gas analyzer for measuring CO and NO_x and Bosch Smoke Meter is used to measure smoke emission.

III. Response Surface Methodology

This method Response surface methodology (RSM) will introduce in 1951 by G.E.P. Box and K. B. Wilson. Is a collection of statistical and mathematical techniques used for developing, improving and optimizing processes. RSM is usable for sequence of designed experiments and an optimal response is obtaining. A study through Response surface Methodology is made for the checking of performance and exhaust emission parameters of diesel engine. They are BSFC (Brake specific fuel consumption), BTE (brake thermal efficiency), CO (carbon monoxide), HC (unburnt- hydrocarbon), NO_x (nitrous oxide), and Smoke. Using RSM the effect of blending ratio and load torque on these performance and emission parameters are studied using RSM. The steps involved in research work are given below:-

1. Identification of important process control variables is done using RSM.
2. Then lower and upper value of different control variables is found out.
3. The design matrix is developed by using Central Composite Rotatable Design (CCRD).
4. The response of different variables is recorded.
5. Second-order quadric model is developed by using RSM.
6. The adequacy of model developed is checked.
7. Then significance of regression coefficient tested.
8. Presenting the main effects and the significant interaction effects of the process parameters on the responses in the three-dimensional (surface) graphical form.

IV. Results and Discussions

Response Surface Methodology (RSM) is used for the optimization of brake specific fuel consumption, unburnt hydrocarbons, carbon monoxide, brake thermal efficiency, nitrous oxide, and smoke. Then the selection of sample pointsis done in such a way that with minimum number of experiments a sufficiently accurate model is generated. “Design Expert”, a statistical software is used for the selection of appropriate model and the development of response surface models. For the different response characteristics, viz., brake specific fuel consumption, brake thermal efficiency, carbon monoxide, un-burnt hydrocarbons, nitrous oxide, and smoke, regression equations are obtained for the selected model. These regression equations which were developed using RSM and were plotted to investigate the effect of process variables on various response characteristics. For the statistical analyzation, the analysis of variance (ANOVA) was performed.

Table 5.1: Experimental Results and Experimental Design Matrix of the Performance and Emission Responses from Waste Cooking Biodiesel.

Run	Factor 1 A:Blending Ratio %V/V	Factor 2 B:Load torque Nm	R 1 BSFC (kg/kWh)	R2 BTE (%)	R 3 CO (vol%)	R 4 NOx (ppm)	R 5 HC (PPM)	R 6 Smoke (vol%)
1	30	20	0.426	35.04	0.089	228	8.9	7.2
2	20	25	0.312	34.74	0.0379	213	4.52	3.8
3	30	20	0.426	35.04	0.089	228	8.9	7.2
4	30	12.93	0.362	31.36	0.042	213	1.74	3.1
5	30	20	0.426	35.04	0.089	228	8.9	7.2
6	40	15	0.248	31.84	0.0389	206	2.92	2.1
7	15.86	20	0.275	29.58	0.028	201	6.28	1.7
8	30	20	0.426	35.04	0.089	228	8.9	7.2
9	44.14	20	0.199	30.63	0.063	208	4.38	2.5
10	30	27.07	0.189	33.65	0.083	226	5.39	3.7
11	20	15	0.416	26.64	0.049	197	3.59	3.3
12	30	20	0.426	35.04	0.089	228	8.9	7.2
13	40	25	0.259	31.27	0.057	217	3.18	4.7

5.1.2 Effect of Process Variables on Performance & Emission Parameters

BSFC = -0.66337 +0.033219 * Blending ratio+0.073709* Load torque -8.13750E-004 * Blending ratio2 -2.48500E-003* Load torque2 +5.75000E-004* Blending ratio * Load torque

BTE = -41.18800 +2.41506* Blending ratio +3.67071 * Load torque -0.025131* Blending ratio2 -0.052525* Load torque2 -0.043350* Blending ratio * Load torque

CO = -0.33745 +0.012106* Blending ratio +0.021765* Load torque -2.38250E-004* Blending ratio2 -6.13000E-004* Load torque2 +1.46000E-004* Blending ratio * Load torque

HC = -58.86331 +1.21354* Blending ratio +4.88530* Load torque -0.020088* Blending ratio2 -0.11565* Load torque2-3.35000E-003* Blending ratio * Load torque

NO_X = -15.46720 +8.39874* Blending ratio +10.18462* Load torque -0.12687* Blending ratio2 -0.20750* Load torque2 -0.025000* Blending ratio * Load torque

Smoke = -37.60478 +1.22164 * Blending ratio +2.53371* Load torque -0.023688* Blending ratio2 -0.068750* Load torque2 +0.010500* Blending ratio * Load torque

5.1.3 Analysis of Variance (ANOVA) for Waste Cooking Biodiesel

In order to statistically analyze the results, ANOVA was performed. Process variables having p-value<0.05 are considered significant terms for the requisite response characteristics.Table 5.1 lists the experimental factors setting and results on the basis of the experimental design. All 13 experiments were conducted and results were analyses by multiple regression.

The coefficients of the full model were extracted via regression analysis and were tested for significance. And finally, best fitted model was evaluated via regression. Two linear coefficients (A, B) yielded by analysis of regression, one cross-products coefficients (AB) and two quadratic coefficients (A^2, B^2) and one block term for the full model as in table 5.8.

Table 5.8: ANOVA for Waste Cooking Biodiesel BSFC

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob>F	
Model	0.096	5	0.019	13.43	0.0018	significant
A-Blending Ratio	0.013	1	0.013	9.44	0.0180	
B-Load Torque	0.014	1	0.014	9.98	0.0160	
A^2	0.046	1	0.046	32.25	0.0008	
B^2	0.027	1	0.027	18.80	0.0034	
AB	3.306E-003	1	3.306E-003	2.31	0.1720	

Residual	9.998E-003	7	1.428E-003			
Lack of Fit	9.998E-003	3	3.333E-003			
Pure Error	0.000	4	0.000			
Cor Total	0.11	12				

1) The Model F-value of 13.43 implies the model is significant. There is only a 0.18% chance that a "Model F-Value" this large could occur due to noise.
2) Values of "Prob > F" less than 0.0500 indicate model terms are significant.
3) In this case A, B, A^2, B2 are significant model terms.
4) Values greater than 0.1000 indicate the model terms are not significant.
5) If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 5.9: ANOVA for Waste cooking Biodiesel BTE

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob>F**	
Model	85.395	5	17.08	50.31	< 0.0001	significant
A-Blending Ratio	1.29	1	1.29	3.81	0.0920	
B-Load Torque	14.50	1	14.50	42.70	0.0003	
A^2	43.94	1	43.94	129.43	< 0.0001	
B^2	12.00	1	12.00	35.34	0.0006	
AB	18.79	1	18.79	55.36	0.0001	
Residual	2.38	7	0.34			
Lack of Fit	2.38	3	0.79			
Pure Error	0.000	4	0.000			
Cor Total	87.76	12				

1) The Model F-value of 50.31 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.
2) Values of "Prob > F" less than 0.0500 indicate model terms are significant.
3) In this case B, A^2, B2, AB are significant model terms.
4) Values greater than 0.1000 indicate the model terms are not significant.
5) If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 5.10: ANOVA for Waste cooking Biodiesel CO emission

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob>F**	
Model	6.174E-003	5	1.235E-003	12.95	0.0020	significant
A-Blending Ratio	4.277E-004	1	4.277E-004	4.48	0.0720	
B-Load Torque	5.278E-004	1	5.278E-004	5.53	0.0509	
A^2	3.949E-003	1	3.949E-003	41.40	0.0004	
B^2	1.634E-003	1	1.634E-003	17.13	0.0044	
AB	2.132E-004	1	2.132E-004	2.23	0.1786	
Residual	6.677E-004	7	9.538E-005			
Lack of Fit	6.677E-004	3	2.226E-004			
Pure Error	0.000	4	0.000			
Cor Total	6.842E-003	12				

1) The Model F-value of 12.95 implies the model is significant. There is only a 0.20% chance that a "Model F-Value" this large could occur due to noise.
2) Values of "Prob > F" less than 0.0500 indicate model terms are significant.
3) In this case A^2, B2 are significant model terms.
4) Values greater than 0.1000 indicate the model terms are not significant.
5) If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 5.11: ANOVA for Waste cooking Biodiesel NO_X emission

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob>F**	
Model	1537.40	5	307.48	55.75	< 0.0001	significant
A-Blending Ratio	65.55	1	65.55	11.89	0.0107	
B-Load Torque	257.47	1	257.47	46.69	0.0002	
A^2	1119.81	1	1119.81	203.05	< 0.0001	
B^2	187.20	1	187.20	33.94	0.0006	
AB	6.25	1	6.25	1.13	0.3224	
Residual	38.60	7	5.51			
Lack of Fit	38.60	3	12.87			
Pure Error	0	4	0			
Cor Total	1576.00	12				

1) The Model F-value of 55.75 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.
2) Values of "Prob > F" less than 0.0500 indicate model terms are significant.
3) In this case A, B, A^2, B2 are significant model terms.
4) Values greater than 0.1000 indicate the model terms are not significant.
5) If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 5.12: ANOVA for Waste cooking Biodiesel HC emission

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob>F**	
Model	84.91	5	16.98	32.73	0.0001	significant
A-Blending Ratio	2.76	1	2.76	5.32	0.0545	
B-Load Torque	5.04	1	5.04	9.72	0.0169	
A^2	28.07	1	28.07	54.11	0.0002	
B^2	58.15	1	58.15	112.10	< 0.0001	
AB	0.11	1	0.11	0.22	0.6560	
Residual	3.63	7	0.52			
Lack of Fit	3.63	3	1.21			
Pure Error	0	4	0			
Cor Total	88.54	12				

1) The Model F-value of 32.73 implies the model is significant. There is onlya 0.01% chance that a "Model F-Value" this large could occur due to noise.
2) Values of "Prob > F" less than 0.0500 indicate model terms are significant.
3) In this case B, A^2, B2 are significant model terms.
4) Values greater than 0.1000 indicate the model terms are not significant.
5) If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

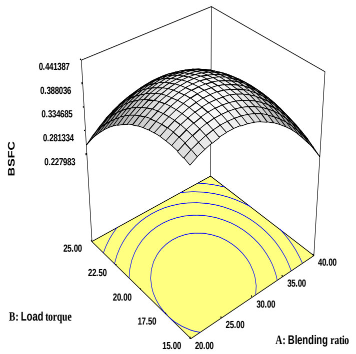
Table 5.13: ANOVA for Waste cooking Biodiesel Smoke emission

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob>F**	
Model	56.245	5	11.25	40.56	< 0.0001	significant
A-Blending Ratio	0.086	1	0.086	0.31	0.5941	
B-Load Torque	1.95	1	1.95	7.03	0.0329	

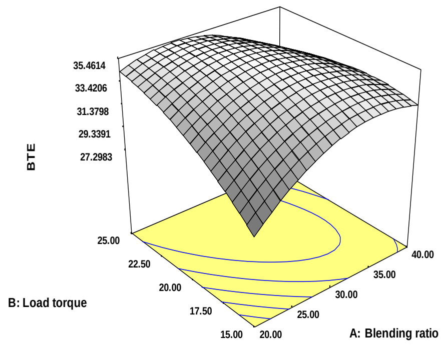
A^2	39.03	1	39.03	140.77	< 0.0001	
B^2	20.55	1	20.55	74.11	< 0.0001	
AB	1.10	1	1.10	3.98	0.0864	
Residual	1.94	7	0.28			
Lack of Fit	1.94	3	0.65			
Pure Error	0.000	4	0.000			
Cor Total	58.18	12				

1) The Model F-value of 40.56 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.
2) Values of "Prob > F" less than 0.0500 indicate model terms are significant.
3) In this case B, A2, B2 are significant model terms.
4) Values greater than 0.1000 indicate the model terms are not significant.
5) If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

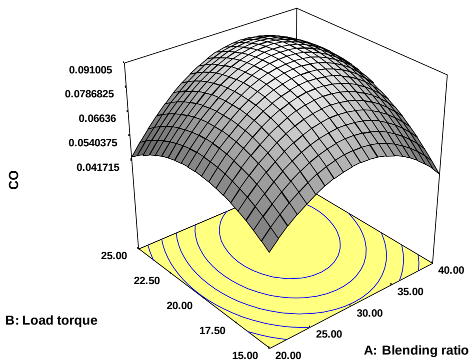
A



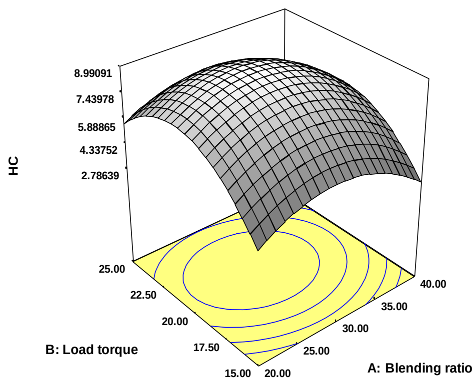
B



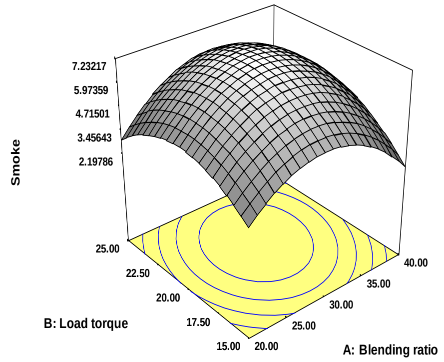
C



D



E



F

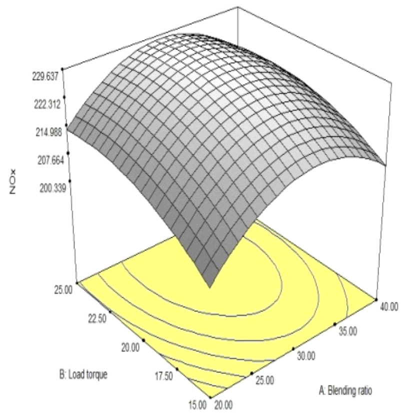


Fig 5.1 Response surface plot of the BSFC, BTE, CO, HC, NOx and Smoke from Waste cooking Biodiesel as affected by Blending Ratio and Load Torque

V. Conclusion

The work has been done to study the production of biodiesel, optimization of performance and emission parameters of Waste cooking biodiesel. The conclusion drawn on the basis of results are:

1. For the Waste cooking biodiesel, B20 is recommended by the development of experimental design using Response Surface Methodology based CCRD.
2. The design points for the curve fittings from Design-Expert 6.0 are blending ratio of 20 and load torque of 25 Nm.
3. The experiment has been performed (THRICE) to confirm the validation of experiment at optimum conditions (blending ratio 20, load torque 25 Nm) was obtained. The average value of performance and emission parameters was closer to the predicted value.

References

[1] Lokesh, K., Deepak, K., Avinash, A. “Performance evaluation of a vegetable oil fuelled compression ignition engine”, Renewable Energy, 2008, 1147-1156.

[2] Sims, R.E.H. “Tallow esters as an alternative diesel fuel”, Trans ASAE, 1985, 16-21.

[3] Demirbas A. “Progress and recent trends in biodiesel fuels” Energy Conversion and Management, 2008, 14-34.

[4] Maheshwari N, Balaji C, Ramesh A. A nonlinear regression based multi-objective optimization of parameters based on experimental data from an IC engine fueled with biodiesel blends. Biomass & Bioenergy 2011;35:2171-83.

[5] Lakshmi CV, Viswanath K, Venkateshwar, Satyavathi B. Mixing characteristics of the oil-methanol system in the production of biodiesel using edible and non-edible oils. Fuel Processing Technology 2011;92:1411-7.

[6] Wang, Z., Zhang, T., Yuan, Y. “Combustion and emission of the diesel engine using bio-diesel fuel”, Front. Mech. Eng. China, 2008, 189-192.

[7] Jones JC. Methyl ester of karanja oil as an alternative energy source. Fuel 2008;87:2846.

[8] Kannan, G.R., R. Anand. 2012. Effect of injection pressure and injection timing on DI diesel engine fuelled with biodiesel from waste cooking oil. Biomass & Bioenergy 1-10.

[9] Fan, Xiaohu, Rachel Burton, Greg Austic. 2010. Conversion of degummed soybean oil to biodiesel: Optimization of degumming methods and evaluation of fuel properties. International journal of green energy 7:593-99

[10] Adaileh, Wali M., and Khaled S. AlQdah. 2012. Performance of diesel engine fuelled by a biodiesel extracted from a waste cooking oil. Energy Procedia 18:1317-34.

[11] Tewari, P.G., Banapurmath, N.R., Hosmath, R.S. “Performance and emission characteristics of DI compression ignition engine operated on Honge, Jatropha and sesame methyl esters”. Renewable Energy, 2008, 1982-1988.

[12] Shahadat, Z., Nuran, N.M., Shamim, A. M., Mhia, M. “Improvement of engine emission with conventional diesel fuel and diesel-biodiesel blends”, Bioresource Technology, 2006, 372-378.

[13] Demirbas, A., Karslioglu, S. “Biodiesel production facilities from vegetable oils and animal fats”, Energy Sources, Part A:

Recov; Utili. & Environ. Effects, 2007, 133-141.

[14] Wang JX, Chen KT, Wu JS, Wang PH, Huang ST, Chen CC. Production of biodiesel through transesterification of soybean oil using lithium orthosilicate solid catalyst.; 2012.

[15] Lakshmi CV, Viswanath K, Venkateshwar, Satyavathi B. Mixing characteristics of the oil-methanol system in the production of biodiesel using edible and non-edible oils. Fuel Processing Technology 2011;92:1411-7.

[16] Thiruvengadaravi KV, Nandagopal J, Baskaralingam P, Bala VSS, Sivanesan S. Acid-catalyzed esterification of karanja (Pongamia Pinnata) oil with high free fatty acid for biodiesel production. Fuel 2012;98:1-4.

[17] Bala VSS, Thiruvengadaravi KV, Kumar PS, Premkumar MP, et al. Removal of free fatty acid in Pongamia Pinnata (Karanja) oil using divinylbenzene-styrene copolymer resins for biodiesel production. Biomass and Bioenergy 2012;37:335-41.

[18] Wang R, Zhou WW, Hanna MA, Zhang YP, Bhadury PS, Wang Y, et al. Biodiesel preparation , optimization, and fuel properties from non-edible feedstock, Datura stramonium L. Fuel 2012;91:182-6.

[19] Corro G, Tellez N, Banuelos F, Mendoza ME. Biodiesel from Jatropha Curcas oil using Zn for esterification step and solar radiation as energy source. Fuel 2012;97:72-9.

[20] Ali, Y., Hanna, M.A. “Physical properties of tallow ester and diesel fuel blend”, Bioresource Technology, 1994, 31-34.

[21] Rutto, Hilary Limo, & Christopher Chintua Enweremadu, 2011. Optimization of production variables of biodiesel from manketti using response surface methodology. International journal of green energy 8:768-79.

[22] Duan, X., J. Peng, C. Srinivasakannan, L. Zhang, H.Xia, K. Yang, Z. Zhang. 2011. Process optimization for the preparation of activated carbon from jatropha hull using response surface methodology. Energy Sources 3:2005-17.

[23] Shahadat, Z., Nuran, N.M., Shamim, A. M., Mhia, M. “Improvement of engine emission with conventional diesel fuel and diesel-biodiesel blends”, Bioresource Technology, 2006, 372-378.

[24] hobadian B.and Rahimi H., Nikbakht A.M. , Najafi G. , Yusaf T.F.. “Diesel engine performance and exhaust emission analysis using waste cooking biodiesel fuel with an artificial neural network”. Renewable Energy 976–982,34