Enhancing Combustion Aspects of DI Engine using Tapioca Sludge treated poultry waste biogas + Tyre Pyrolysis Oil + Cerium Oxide blended Bio fuel

S. Kesavan[1], R. Sasikumar[2], S Siddharth[3]
[1]Mechanical Engineering, SRG Engineering College, Namakkal, India, E-mail: sailorkesav87@gmail.com
[2]Mechanical Engineering, Selvam College of Technology, Namakkal, India, E-mail: sasikalipatty@gmail.com
[3]Mechanical Engineering, University College of Engineering, BIT Campus, Anna University Tiruchirappalli, Email: sksmsiddharth1@yahoo.in

Abstract

The present rate of depletion of conventional fuels has led the researchers to identify different types of bio fuels. In this present research, an attempt has been made to enhance the performance aspects of Direct Injection Engine, by substituting Tapioca Sludge treated biogas in air and blending Tyre Pyrolysis Oil with diesel. Using Central Composite Design model, 20 different experiments were conducted by using different combinations of Tapioca Sago Sludge treated poultry waste + Air and Tyre Pyrolysis Oil incorporated diesel + Cerium Oxide Nano particle addition, time taken for consumption for 10 cc of fuel and Load given to the engine. The purpose was to enhance the brake thermal efficiency and reduce the emissions. Empirical relationships were developed by using second order regression polynomial equations. Using Analysis of variance, the significance of the developed model was ascertained. Using response surface methodology, the model was optimized. The difference between the predicted and optimized Tapioca Sago Sludge treated poultry waste biogas + Tyre Pyrolysis Oil incorporated diesel + Cerium Oxide Nano particle, fueled Direct Ignition Engine model was less than 3 %, which indicated that the model was developed with very high predictability.

Keywords: *Biogas, Tyre Pyrolysis Oil, Optimization, Cerium Oxide.*

1. Introduction

In this present world, a lot of issues are being created owing to excessive combustion of fossil fuels. It has made the researchers to conduct experiments so as to identify different type of biofuels for reducing the dependence on fossil fuels.

Tagliavini et al. (2018) conducted an exhaustive review on bio fuels and the effect of using these fuels on the environment and ecosystem as a whole. The importance of using bio fuels on enhancement of engine performance, without much modifications in the design aspects of engine [1]. Dhinesh et al. (2018) conducted performance evaluation experiments by using diesel engine. The efficiency of the engine was enhanced by using nano particle incorporated biofuel. By increasing the blend of nanoparticle infused bio fuel, emissions were significantly reduced [2]. Czekala et al. (2018) evaluated the combustion efficiency and emission aspects of bio fuels which were prepared from sawdust and digestate. By using fuel evaluation techniques, the gross calorific value of the fuel was identified [3]. Hess at al. (2018) conducted experimental evaluation of the quality aspects of bio fuels which were prepared from micro algae. The effect of contamination induced in the bio fuel owing to the deterioration of micro algae [4]. Negm et al. (2018) attempted to produce bio fuel by using Jatropha oil and the efficiency of transesterification was improved by using heterogeneous catalysts [5]. From study of previous literatures, studies on Direct Injection Engine performance enhancement by using Tapioca Sago Sludge treated biogas, Tyre Pyrolysis Oil with Cerium Oxide Nano particles, was not found. So, in this investigation, an attempt was made to improve the engine performance and reduce emissions by using Tapioca Sago Sludge treated biogas, Tyre Pyrolysis Oil with Cerium Oxide Nano particles.

2. Materials and Methods

The present research investigation has been conducted using three different setups. The first one is the anaerobic digestion system using Continuous Stirred Tank Reactor Setup for production of biogas from sago sludge treated poultry waste. The second one is the Pyrolysis reactor used for conversion of waste tyres into Tyre Pyrolysis Oil. The third one is the Diesel Engine test rig.

In this research poultry waste manure was used for production of biogas. In South India, specifically in Namakkal and Karur districts, lots of poultry farms are available and every year tons of poultry wastes are being dumped. The biomass collected in the form of poultry waste manure was subjected to proximate and ultimate analysis and the constituents in the poultry waste manure and its energy values have been given in Table 1.

Table 1 Composition of Poultry waste manure and its energy values

Parameter	Dry Poultry waste
Moisture % 7.3	6.3 %
Carbon (Fixed)	5.2 %
Volatile Matter	54.7 %
Ash content	33.8 %
Carbon	26.2 %
Hydrogen	2.5 %
Nitrogen	5.7 %
Oxygen	23.25 %
Sulphur	0.25 %
Calorific Value (Lower)	8157.136 kJ/kg
Calorific Value (Higher)	8221.425 kJ/kg
Ash Deformation Temperature	863°C
Ash Fusion Temperature	916°C

For enhancing the effectiveness of production of biogas, tapioca sago sludge was used to treat the poultry waste manure. Sago was grown in Tamil Nadu from the time of independence. For pulping its roots, it was grown in cottage scale. Tapioca Sago roots collected from the fields are thoroughly washed in water for removal of impurities and other dirt. After cleaning, the outer skin was peeled and crushed. The important aspects of Tapioca Sago Sludge have been presented in Table 2.

Table 2 Important aspects of Tapioca Sago Sludge

Properties	**Values**
pH	7.6
T. Alkalinity	391 mg/l
T. Acidity	391 mg/l
Dissolved oxygen	2.6 mg/l
COD	27650 mg/l
BOD	8160 mg/l

Biogas was prepared from tapioca sago sludge treated poultry waste. An indigenously developed bio gas plant was used for the anaerobic fermentation process. The purpose of mixing tapioca sago sludge in the poultry waste was to increase the methane content in the obtained biogas. The fixed dome collector biogas plant used for the research has been indicated in Figure 1. For enabling better anaerobic fermentation so as to quickly and efficiently make the tapioca sago sludge treated waste to undergo Hydrolysis till Methanogenesis, Continuous Stirred tank reactor setup was used. The digester vessel was placed in a temperature controlled environment such as an incubation chamber.

Figure 1 Biogas plant

From waste Tyres, using pyrolysis process, Tyre Pyrolysis Oil was obtained. The Pyrolysis equipment used for conversion of waste tyres to oil has been indicated in Figure 2.

Figure 2 Tyre Pyrolysis Plant

Using a rotary type of reactor, pyrolysis of waste tyres were done. The overall length of the reactor was 6.5 m and 3 m in diameter. The rotation of the reactor was done using electrical motors. Initial combustion was started by using wood and then heat retention was done by using coal. Using fasteners, the front door was locked so as to enclose the volume of the added waste tyres. Using sealing element, the rear side of the reactor was connected. An oil separator was placed through which the volatile vapor formed was passed, to separate heavy oil, which was collected in the oil tank because of gravity. At the outlet of the oil separator, series of water cooled pipes were connected through a damper, through which the volatile vapor condenses to form liquid. Using cooling towers, the temperature was reduced to near room temperature. The volatile vapors produced at 1600°C was reduced sequentially to condense to room temperature in the pyrolysis plant setup.

Using Co-precipitation method, cerium oxide nanoparticles were obtained from Ce(III) precipitate. 0.02 M Ce(III) nitrate solution was prepared by using 2.16 grams of $Ce(NO_3)_3.6H_2O$, in one fourth liter of distilled water. 0.03 M K_2CO_3 solution was formed by mixing 1.036 g of K_2CO_3 in one fourth lite of distilled water. Cerium (III) carbonate was obtained by mixing 50 ml of Ce(III) nitrate and 20 ml of potassium carbonate to 100 ml of water. During the entire precipitation process, ph value was maintained as 6. At 65°C, the obtained cerium oxide Nano powder was dried for a duration of 2 hrs. After 2 hrs., it was brought to room temperature before ageing. At 220°C, it was aged for 2.5 hrs. and calcined at 600°C for 3 hours.

Using a DI engine setup, the combustion experiments were conducted. The engine was Kirloskar make. It possessed single cylinder having four strokes. It was air cooled. The cylinder capacity was 661 cc. the cylinder bore was 87.5 mm and the length of stroke was 110 mm. At a constant running speed of 1500 rpm, the rated power output was 5.2 kW. The normal compression ratio was 17.5:1. The normal injection pressure was 200 bar. The injection timing was 23°CA. The actual test engine setup has been shown in Figure 3.

Figure 3 DI engine setup

2.1 Feasible Process Parameter Selection

In this investigation, an attempt was made for optimization of combustion parameters to enhance the direct injection engine efficiency and reduce the emissions. From previous literatures, the feasible combination of Tapioca Sago Sludge Treated Poultry Waste Biogas to Air ratio was fixed at 30:70. The feasible ratio for Tyre Pyrolysis Oil Blend with Diesel was found to be 35:65. For further evaluation, both the proportions were maintained constant throughout the research evaluation.

To this blend, Cerium Oxide Nano particles were added. As the addition in Cerium Oxide Nano particle fluctuated the blend aspects, Mass of Cerium Oxide Nano particle in mg (MCO) was considered as an important process parameter. The next process parameters were the time duration required for consumption of 10 cc of 35% Tyre Pyrolysis Oil to 65% Diesel fuel blend (T) and Load given to the engine (L). By initial trial and error experiments, and evaluating the previous literature the feasible limits of the three process parameters were found.

For identifying the minimum possible value and the maximum possible value, two of the process parameters were maintained at constant value and the third parameter was fluctuated. From the experimental trials, the following observations were made.

i) If the Mass of Cerium Oxide particle per liter (MCO) of the fuel blend was lesser than 1.5 mg, no measurable decrease in emissions were observed.

ii) If the Mass of Cerium Oxide particle per liter (MCO) of the fuel blend was greater than 5.5 mg, undesirable sticking of Cerium Oxide Nanoparticles causes turbidity, thereby reducing the performance of the engine.

iii) If the flow of fuel was reduced so that the time taken for 10 cc fuel consumption (T) was more than 75 seconds, lack of enough fuel flow causes improper combustion thereby reducing the overall engine performance.

iv) If the flow of fuel was increased so that the time taken for 10 cc fuel consumption (T) was less than 35 seconds, excessive flow of fuel during very short duration causes wastage of fuel without proper combustion, thereby reducing combustion efficiency.

v) If the load given to the engine (L) was lesser than 2 kgf, the performance of the engine was not proper.

vi) If the load given to the engine (L) was greater than 8 kgf, the excessive loading caused undesirable increase in NOx and unburnt fumes.

It could be observed that from Cerium Oxide Nano Particle addition of 1.5 mg to 5.5 mg per liter of fuel blend, time duration for consumption of fuel from 35 seconds to 65 seconds and load given to the engine from 2 kgf to 8 kgf the efficiency of the engine was found to be better. The process parameter values have been indicated in Table 3

Table 3 Process Parameter value and their levels for Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air combination Direct Ignition combustion

No	**Parameter**	**Notation**	**Unit**	**Levels**				
				-1.68	**-1**	**0**	**1**	**+1.68**
1	Mass of Cerium Oxide particle per liter	MCO	Mg	1.5	2.3	3.5	4.6	5.5
2	Time for 10 cc fuel	T	sec	35	43.1	55	66.8	75
3	Load given to engine	L	kgf	2	3.2	5	6.7	8

2.2 Developing design matrix

As the total number of factors used in the research was more, a three factor face centered, five level central composite design model was used. The range of values were varied from -1.68 to +1.68. the uppermost limit was fixed at a coded positive value of +1.68. The least and lowest value was fixed at -1.68. A rotatable central composite design model was developed using Design Expert. With an appreciably high confidence level, from the developed significant values, the final relationship was compared (Montogomery DC 2001) [6]

$C_i = 1.682[2C – (C_{max} + C_{min})/(C_{max} + C_{min})]$ --- (1)

In the above equation, the coded value of C was C_i. From the value varying from C_{min} to C_{max}, C was made to assume any of the variable's value. The lowest value of the coded parameter was determined to be C_{min} and the maximum value of coded parameter value was termed as C_{max}. The central composite matrix formulated with twenty different experimental conditions have been indicated in Table 4.

Table 4 – Range of central composite design model of Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air combination Direct Ignition combustion model

No Run	Actual factor value			BTE %	UHC ppm
	MCO Mg	T sec	L Kgf		
1	3.5	55.0	8.0	39.5	57.0
2	3.5	55.0	2.0	36.8	38.2
3	4.6	66.8	3.2	37.9	37.7
4	3.5	35.0	5.0	37.6	52.7
5	3.5	55.0	5.0	39.7	30.2
6	4.6	43.1	3.2	37.4	49.5
7	3.5	55.0	5.0	39.7	25.9
8	2.3	43.1	6.7	37.9	51.1
9	4.6	66.8	6.7	38.5	61.3
10	3.5	75.0	5.0	39.0	41.5
11	4.6	43.1	6.7	41.0	59.7
12	3.5	55.0	5.0	39.8	28.6
13	2.3	66.8	6.7	39.0	46.8
14	1.5	55.0	5.0	37.9	52.2
15	2.3	66.8	3.2	39.3	39.3
16	5.5	55.0	5.0	39.4	57.5
17	3.5	55.0	5.0	39.8	27.0
18	3.5	55.0	5.0	39.7	29.7
19	2.3	43.1	3.2	35.0	59.1
20	3.5	55.0	5.0	39.5	29.1

2.3 Recording of responses

The value of Brake thermal efficiency (BTE) for Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air combination Direct Ignition Combustion Engine was evaluated for the various running conditions and they have been indicated in Table 6.2. Using exhaust gas evaluation methods, the extent of unburnt hydrocarbon (UHC) present in the emissions were evaluated and the values have been indicated in Table 4.

Between Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air combination Direct Ignition combustion process parameter values and responses, relationships were developed in empirical form. The responses were observed in the form of Break Thermal Efficiency (BT) in % and the Unburnt Hydrocarbon (UHC) content by using AVL exhaust gas evaluation.

These responses were attributed to be functions of the important Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air combination process parameters such as Mass of Cerium Oxide Nano particle addition in mg, duration in seconds for consumption for 10 cc fuel and the load given to the engine.

3. Results and Discussion

3.1 Developing empirical relationships

As per the relationship indicated by (Paventhan et al. 2011), the equations for brake thermal efficiency and are given as follows [7]

BTE = f (MCO, T, L) -------- (2)

UHC = f (MCO, T, L) -------- (3)

The response surface K of the Brake Thermal Efficiency (BTE) and Unburnt Hydrocarbons (UHC) of the Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air combination are represented by using a polynomial regression equation of second order.

$K = d_0 + \Sigma d_i x_i + \Sigma d_{i1} x_{i2} + \Sigma d_{ij} x_i x_j$ --------(4)

For Cerium Oxide Nano Particle addition (MCO) in mg, time duration for consumption of fuel (T) and load given to the engine (L), the second order polynomial equation is as follows

$BTE/UHC = \{d_0 + d_1 (MCO) + d_2 (T) + d_3 (L) + d_{12} [MCO \times T] + d_{13} [MCO \times L] + d_{23} [T \times L] + d_{11} (MCO)^2 + g_{22} (T)^2 + g_{33} (L)^2\}$ --------- (5)

d_0 is the average of all responses. The coefficients of the regression equation d_1, d_2, d_3 and g_{nn} depends upon the various types such as linear term, interaction term and squared terms of the three input factors. Design expert software was used for identifying the coefficients of the different variables. The significance of the individual coefficient values of Brake Thermal Efficiency and Unburnt Hydrocarbons were identified using student t tests and p values.

Analysis of variance (ANOVA) method was used for evaluating maximization of break thermal efficiency model and Hydrocarbon content minimization model. The ANOVA test evaluation for break thermal efficiency (BTE) model is indicated in Table 5 and the ANOVA results for Unburnt Hydrocarbon content (UHC) minimization model is indicated in Table 6.

The value of "Prob > F", lesser than 0.05, in both the models, is a very good indication that the developed model is significant at 95 % confidence level. The range of values for which they are greater than 0.10, is a clear indication that the model was found to be insignificant.

Table 5 – ANOVA evaluation for break thermal efficiency model

Source	SS	Df	F – ratio	p-value Prob>F	
Model	34.71	9	568.76	< 0.0001	Significant
B	2.68	1	395.69	< 0.0001	
T	2.38	1	350.95	< 0.0001	
L	9.21	1	1357.63	< 0.0001	
B x T	6.62	1	976.48	< 0.0001	
B x L	0.37	1	54.82	< 0.0001	
T x L	4.69	1	692.11	< 0.0001	
B^2	2.19	1	323.09	< 0.0001	
T^2	3.73	1	549.31	< 0.0001	
L^2	4.51	1	664.52	< 0.0001	
Res	0.068	10			
LOF	0.019	5	0.39	0.8394	No
Std. Dev	0.082	R^2		0.9985	
Mean	38.78	Adj		0.9964	
C.V. %	0.21	Pred		100.420.9912	
PRESS	0.22	Adeq Pres			

Table 6 – ANOVA evaluation for Unburnt Hydrocarbon model

Source	SS	Df	F - ratio	p-value Prob>F	
Model	2901.81	9	129.21	< 0.0001	Significant
B	31.62	1	12.67	0.0052	
T	206.83	1	82.89	< 0.0001	
L	307.37	1	123.18	< 0.0001	
B x T	24.19	1	9.69	0.0110	
B x L	146.84	1	58.85	< 0.0001	
T x L	104.83	1	42.01	< 0.0001	
B^2	1226.41	1	491.48	< 0.0001	
T^2	603.68	1	241.92	< 0.0001	
L^2	640.62	1	256.72	< 0.0001	
Res	24.95	10			
LOF	11.36	5	0.84	0.5755	No
Std. Dev	1.58	R^2		0.9912	
Mean	43.77	Adj		0.9841	
C.V. %	3.61	Pred		0.9635	
PRESS	106.45	Adeq Pres		80.64	

Break thermal efficiency of the Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition engine is indicated as

BTE = +39.7 + 0.44 MCO + 0.42 T + 0.82 L – 0.91 MCO x T + 0.22 MCO x L - 0.77 T x L - 0.39 MCO^2 - 0.51T^2 -0.56L^2 ------------------------- (6)

Hydrocarbon emission of the Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition engine is indicated as

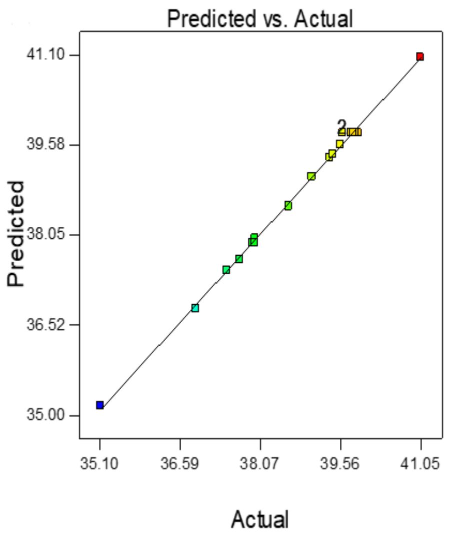
HC = +28.49 +1.52 MCO - 3.89 T +4.74 L + 1.74 MCO x T +4.28 MCO x L +3.62 T x L +9.23 MCO^2 +6.47 T^2 +6.67 L^2 -----------------------(7)

3.2 Adequacy evaluation

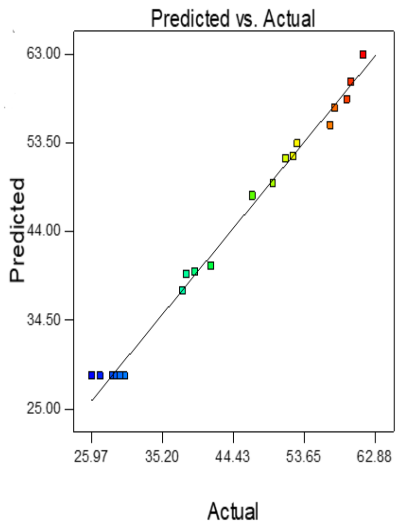
For evaluation of the developed empirical relationship, Analysis of Variance methodology was used. The adequacy of the model which was developed, was verified using response surface. The determination coefficient was identified as the value of R^2.

For the developed Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition engine model for break thermal efficiency and unburnt hydrocarbon model, the value of R^2 indicates the goodness of fit for the value. By evaluating the values obtained from Analysis of Variance for both the models from Table 5 and Table 6, it was found that less than five percent of the values were only left unexplained.

From the ANOVA evaluation, it could be observed that the value of R^2 was found to be high, thereby indicating a very high level of significance for both the developed models. A good level of agreement was found to be present for adjusted coefficient of determination and predicted R^2 value. The adequate precision value could be used for identification of the error that originates between predicted and obtained values.



(a)



(b)

Figure 4 Correlation between predicted and actual values for (a) BTE and (b) UHC emissions

It could be found that the value of determination coefficient was more than 0.95. This is a clear indication that the predicted values were with good correlation with the experimental values of brake thermal efficiency as well as emission of unburnt hydrocarbons. The correlation between the predicted and actual break thermal efficiencies of Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine has been indicated in Figure 4 (a) and that for emissions of unburnt hydrocarbon has been indicated in Figure 4 (b).

3.3 Optimization procedure

With mathematical techniques and statistical methodologies, the relation between the Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process parameters and the output responses were identified. In this investigation, response surface methodology has been used for optimization of Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process parameters. As the number of variables were more, such as the mass of Cerium oxide Nano particle, time duration for consumption of 10 cc of fuel, the loading given to the engine, response surface methodology was found to be highly efficient for identifying the optimized set of process parameters.

The fluctuations found in the dependent variables such as break thermal efficiency and emission of unburnt hydrocarbons were evaluated using response surface methodology.

$G = \Phi (p_1, p_2 \ldots p_k) \pm er.$

The response is indicated by J and the factors in qualitative nature are indicated by $p_1, p_2 \ldots p_k$. A clear indication of the response function could be obtained. In the equation er represent the errors that occurs during experimentation process. The independent variables were represented in a characteristic surface. The co-relation was found to increase on increasing the degree of the polynomial. A major drawback was the increased cost incurred during the experimentation process. Using multiple regression equation, optimization of Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process parameters was done. The independent variables such as the Mass of Cerium Oxide Nano particle addition, time taken for consumption of 10 cc of fuel and load given to the engine were developed as a surface over which the response was fitted.

Circular shapes were used for determination of the dependence between two significant Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process parameters. The responses of the two models were indicated in contour form for identification of the optimized process parameters.

The optimal region for the process parameters were prepared for identification of the optimal region. Simple contours were used for identification of first order models. When the order of the model started to increase, simultaneously the complexity of the contours started to increase. Within the response surface function, the stationary point was characterized.

The function was identified so that the value attained was either maximum, minimum or a saddle point. Characterization of the saddle point was done for optimization of the Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process parameters.

Using design expert software, contours were developed. By evaluation of the shape of the contours, the optimum region could be identified. The independence between the factors was identified by circular contours. Elliptical contours indicate that interaction between the factors were present.

3.4 Analyzing of the developed plots

By using two of the Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process parameters at the middle range and plotting them in the two-reference axis such as Y axis and X axis, the responses such as the brake thermal efficiency and ppm of Unburnt Hydrocarbon emission were recorded in the Z axis. Using 3D surface plots, the optimal point was identified for two process parameters.

The contour plots for brake thermal efficiency model has been indicated in Figure 5. Figure 5 (a) indicates the contour plots for Mass of Cerium Oxide (MCO) and time taken for consumption of 10 cc (T) of fuel blend. Figure 5 (b) indicates the contour plots for Mass of Cerium Oxide (MCO) with Load given to engine (L). Figure 5 (c) indicates the contour plots of 10 cc of fuel blend (T) and load given to the engine (L).

Figure 5 (d) indicates the surface plots for Mass of Cerium Oxide (MCO) and time taken for consumption of 10 cc (T) of fuel blend. Figure 5 (e) indicates the surface plots for Mass of Cerium Oxide (MCO) with Load given to engine (L). Figure 5 (f) indicates the surface plots of 10 cc of fuel blend (T) and load given to the engine (L).

The contour plots for unburnt hydrocarbon emission model has been indicated in Figure 6. Figure 6 (a) indicates the contour plots for Mass of Cerium Oxide (MCO) and time taken for consumption of 10 cc (T) of fuel blend. Figure 6 (b) indicates the contour plots for Mass of Cerium Oxide (MCO) with Load given to engine (L). Figure 6 (c) indicates the contour plots of 10 cc of fuel blend (T) and load given to the engine (L)

Figure 6 (d) indicates the surface plots for Mass of Cerium Oxide (MCO) and time taken for consumption of 10 cc (T) of fuel blend. Figure 6 (e) indicates the surface plots for Mass of Cerium Oxide (MCO) with Load given to engine (L). Figure 6 (f) indicates the surface plots of 10 cc of fuel blend (T) and load given to the engine (L)

The optimized values for Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process parameters were found to be 3.43 mg of Cerium Oxide Nano particle, per litre of fuel blend, time for consumption of 10 cc of fuel as 60 seconds and load of 4.75 kgf, by using response surface methodology.

The predicted maximum break thermal efficiency was found to be 39.78% and the minimum possible unburnt hydrocarbon emission was found to be 27.29 ppm in the exhaust gases. By evaluating the contours and surface plots, it was observed that on increasing the Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process parameter values till a certain extent, brake thermal efficiency increased and unburnt hydrocarbons decreased. On increasing the process parameter values beyond a certain extent, a decrease in brake thermal efficiency and increase in unburnt hydrocarbons was observed.

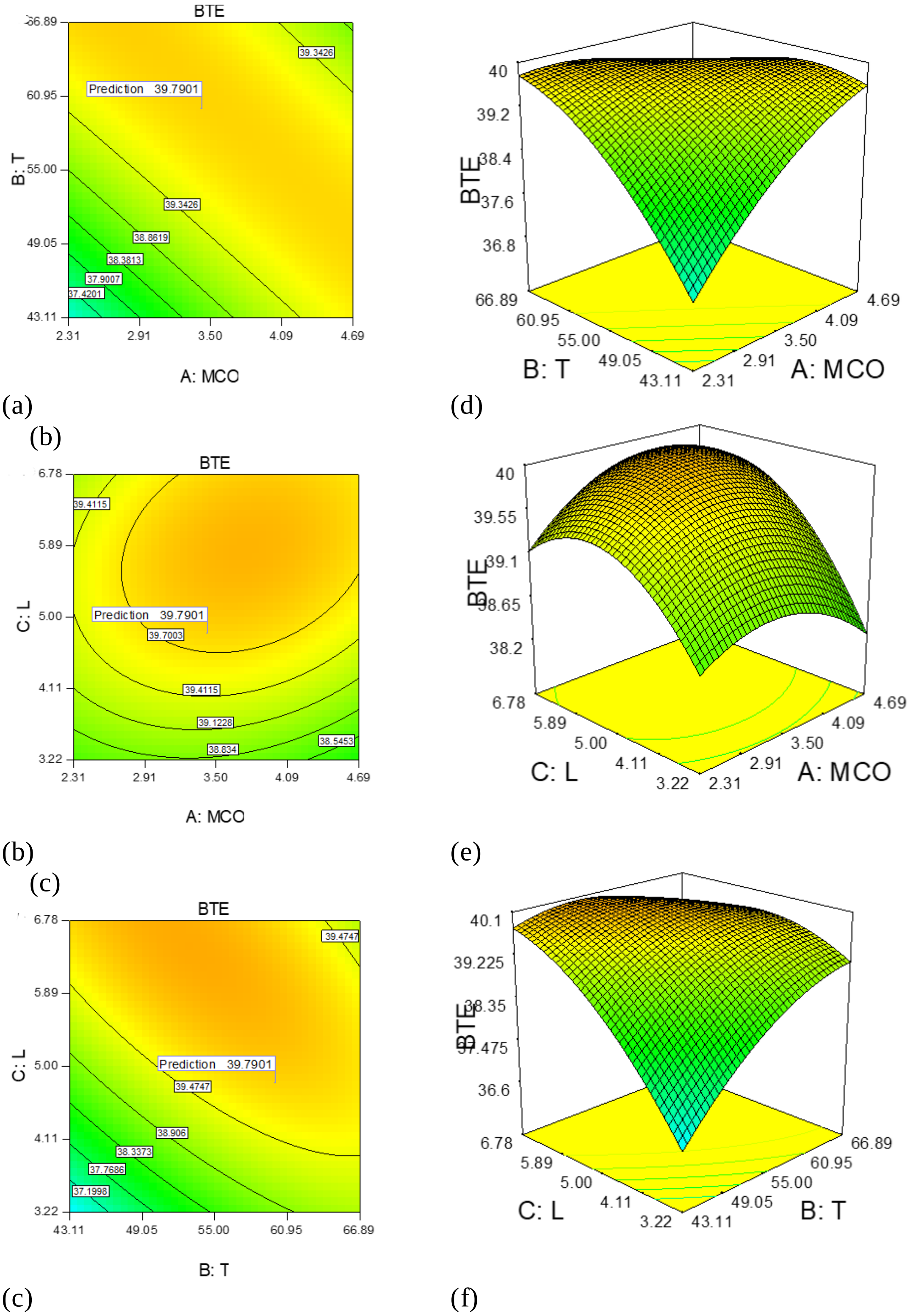


Figure 5 Contour & Surface plots for brake thermal efficiency model

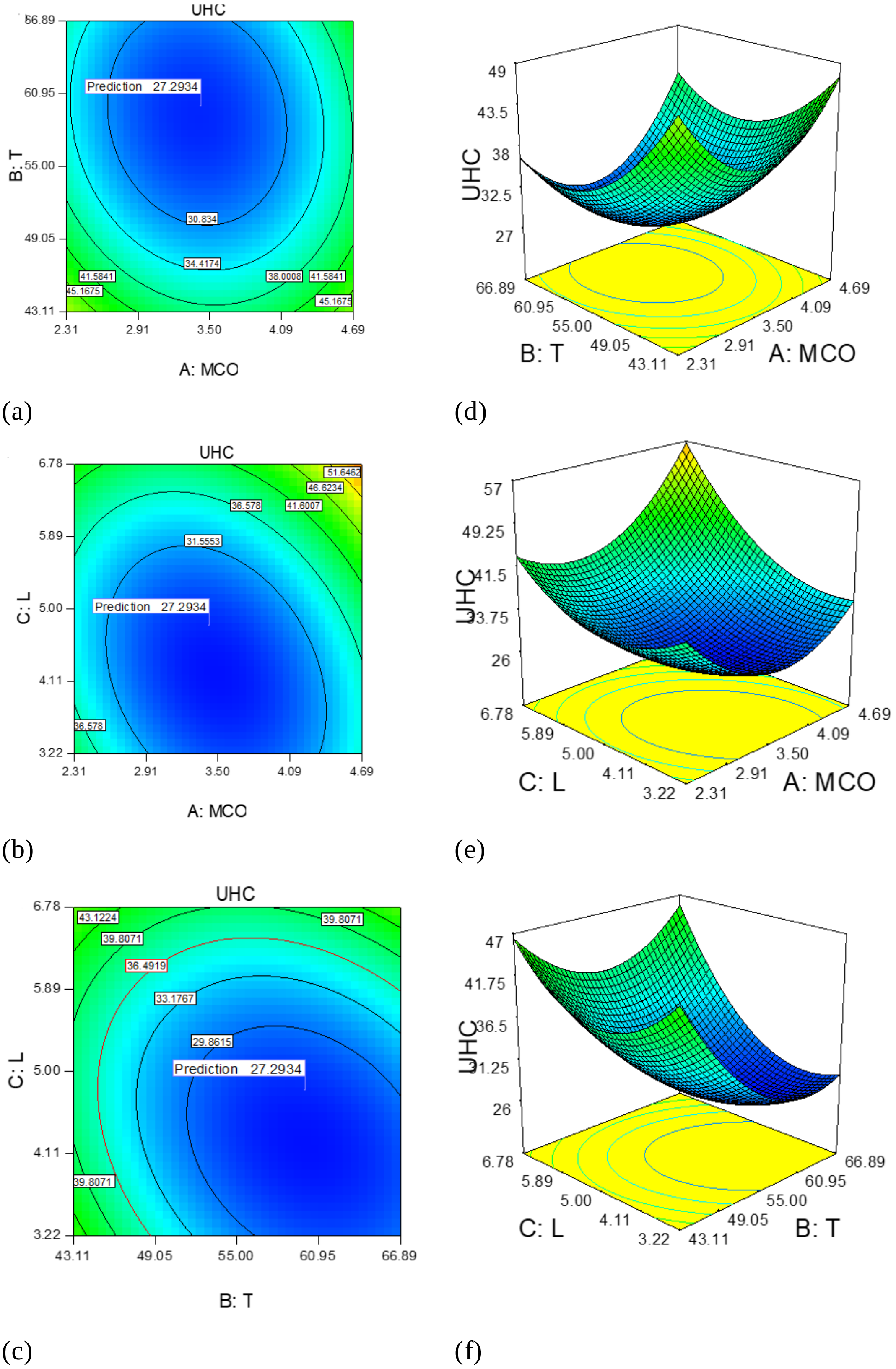


Figure 6 Contour & Surface plots for unburnt hydrocarbon emission model

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3.5 Validation of optimized model

For validating the optimized model, validation experiments were conducted using the optimized set of Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process parameters.

The BTE and UHC was measured while running the engine with optimized set of process parameters. The results of the validation experiments have been indicated in Table 7

Table 7 – Validation experiments and results

Response	Predicted	Experimental	Error
Brake thermal efficiency	39.78%	38.6%	-2.1%
		38.9%	-1.9%
		40.4%	+1.3%
Unburnt Hydrocarbon	27.29 ppm	28.2 ppm	+2.4%
		26.9 ppm	-1.1%
		27.8 ppm	+0.9%

By evaluating the validation experiments it was found that the error between the predicted and actual values were less than 3%. This indicated appreciably high predictability of the Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion.

4. Conclusions

In this chapter, Cerium Oxide Nanoparticle blended TPO + Diesel with Tapioca Sago sludge treated Biogas with air fueled Direct Ignition Diesel engine combustion process were optimized by using response surface methodology. Empirical relationships were developed between the three important parameters such as Mass of Cerium Oxide, Load given to the engine and time duration for 10cc fuel blend, with the responses such as brake thermal efficiency and unburnt hydrocarbon. Using Analysis of Variance, the brake thermal efficiency enhancement model and unburnt hydrocarbon reduction model was developed with more than 95% significance. By evaluating the contour and surface plots, the optimized value of the process parameters was obtained which were validated to a very high level of predictability.

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