Exergy Analysis and Performance Optimization of Diesel Engine Using Diesel-Bael (Aegle Marmelos) Biodiesel Blends With Dimethyl Carbonate Additive Using Response Surface Method

Pitchaiah S[1], Vadivel N[2], Krishnamoorthi M[3]
[1, 3] Dept of mechanical engineering
[2]Assistant Professor, Dept of mechanical engineering
[1, 2,3] Government college of technology,

Abstract- *Renewable energy research in support of the generously developing choice for diesel fuel automobiles has been concentrated because of environmental causes and hurly burly into petroleum combat. The test has been conducted in a light duty single cylinder variable compression ratio (VCR) naturally aspirated multi fuel research engine. In this project, the utilization of bael biodiesel – Diesel blended with dimethyl carbonate (DMC) as an ignition enhancer in a direct injection diesel engine. Better performance and lesser exhaust pollution are the desirable output factors by optimizing the blend ratios and load parameters by factorial design. The confirmatory tests validated that the models developed using response surface methodology (RSM) are adequate to describe the effects of CR, IP, and IT on the performance and emission characteristics using all test fuels. The error in prediction using RSM is within 5%. The regression equations developed for BTE, BSFC, CO, NOX, and HC were found to be statistically significant. Availability equations were applied on varying load experimental results of both diesel and dual fuel modes. The various kinds of availability terms (i.e. shaft, cooling water, exhaust gas and destroyed availability) were compared and discussed.*

Keywords- Diesel, Bael oil, Dimethyl carbonate, Exergy

I. INTRODUCTION

During the last decades, a substantial effort to develop alternative fuel sources, most notably biofuels. Diminishing petroleum reserves and increasing prices, as well as continuously rising concern over energy security, environmental degradation and global warming have been identified as the most influential environmental ones. Hydrocarbon, carbon monoxide, carbon dioxide and oxides of nitrogen are formed in the combustion chambers of these engines and are emitted into the atmosphere[4]. In road particular , biodiesel has received broad attention as an alternate for diesel fuel because it is biodegradable, nontoxic and can significantly reduce exhaust emissions from the engine when burned as a fuel . many researchers show that using biodiesel in diesel engines can reduce hydrocarbon (HC), carbon monoxide (CO),but nitrogen (NO_X) oxide emission may increase .biodiesel can be used in the existing engines with out any engine modifications and the biodiesel obtained from vegetable sources does not contain any metals, aromatic hydrocarbons and sulfur or crude oil residues .biodiesel is an oxyfuel , emission of carbon monoxide and soot tend to reduce[3]. The oxygen content of biodiesel is an important factor in the NO_X formation, because it causes to high local temperatures due to excess hydrocarbon oxidation. The use of vegetable oil as an alternative fuel for internal combustion engines is limited by unfavorable fuel properties, mainly their high viscosity and density, which cause problems in poor fuel atomization, incomplete combustion and ring carbonization in the combustion chamber.these problems can be overcome by four methods :blending, micro emulsion, trans-esterification and pyrolysis. Additional research needs to develop diesel specific additives for better performance, and emission of diesel engines[1]. DMC has required characteristics and projected to improve low temperature flow properties. Earlier studies have recommended that the weight percent of oxygen content in the fuel is the most important factor for opacity reduction.

In this project, the utilization of bael biodiesel – Diesel blended with dimethyl carbonate (DMC) as an ignition enhancer in a direct injection diesel engine. The performance and emission characteristics of the diesel-bael biodiesel blend fuels in diesel engine are compared and analyzed. Studies regarding the investigation of optimum blend ratios for biodiesel blends were reported by researchers. But the current literature concerning the investigation of the optimum diesel – biodiesel , DMC ternary blend ratio at which there is high fuel conversion efficiency and low exhaust emissions are absent..The main technical advantage of optimization for percentage of bio orgin components in diesel fuel is improving the engine performance and exhaust emissions and utilizing optimization blends in a diesel engine without any engine modification such as injector pressure nozzle diameter or injection time[6].

The most extensive applications of RSM are in those situations were several input variables potentially influence some performance measure or the quality characteristics of the process. RSM has been applied for optimization of several chemical and physical processes. Initially, RSM was developed to model experimental responses and then migrated into the modeling of numerical experiments. The nonlinear optimization techniques such as RSM, artificial neural network, genetic algorithm fuzzy logic and taguchi method were used for optimizing the performance and emission characteristics of diesel engine. Minitab'17 software has been used to carry out the optimization analysis by dimensionless desirability response. Depending on the problem in nature the output response has been set either maximum, minimum, in the range, target and/or equal.

Exergy investigation contributes for planning added an efficient thermal system of numerous types and guiding efforts to diminish inefficiencies in thermal structures. The exergy (second law of thermodynamics) diagnoses the sufferers and provides solutions for enhancing the engine performance and engine competence. Exergy losses to thermal loss decreases with lower theoretical air /fuel ratios and will increase just about linearly with advancing in combustion timing , and exergy losses to unburned species decrease noticeably at higher equivalence proportion.

II. MATERIALS AND METHODS

The aegle marmoles (bael) tree is cultivated all over india, predominantly with in sanctuary gardens due to its positions as a sanctified tree, this is likewise true in northern Malaya and srilanka . The bael core seeds containing almost fifty percent oil content. The organic fruits are five to seven centimeter in diameter, stretched out pyriform in shape, with a darkish or yellow casing. The seeds of fifty or more in a fruit are implanted in a thick gummy mash. An oven used to dry the bael seeds at 55°C in a single day to take away excess moistures. After that, the dried seeds are weighted and powered. The mechanical extractor is used toward extract the bael oil and filtered with micron intensity. The resulting bael seed oil is light yellow in color. The DMC of 99% purity purchased from neighborhood business enterprise agent. Bael biodiesel became mixed with diesel and DMC fuel in a blender unit and stirred in an electromagnetic agitator at 500 rpm for 20 min and left for 30 min to accomplish equilibrium at room temperature before the experimental trial.

TABLE 1 Properties of fuels

Blend (%)	Flash point (°c)	Kinematic viscosity at 40°c,cSt	Density (g/cm³)	Calorific value (mj/kg)
Diesel	47	2.246	0.856	43.68
B10	118	4.74	0.859	43.60
B20	124	4.78	0.861	43.59
B17.5DMC2.5	116	4.73	0.860	43.60
B15DMC5	115	4.71	0.863	43.61
B5DMC5	104	4.68	0.858	43.62

2.1 Response surface methodology (rsm**)**

Response surface methodology is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes. With this technique the effect of two or more factors on quality criteria can be investigated and optimum values are obtained. In RSM design there should be at least three levels for each factor. RSM also quantifies relationships among one or more measured responses and the vital input factors. MINITAB software was used to develop the experimental plan for RSM. By conducting experiments and the posterior application of regression analysis model of the response variable of interest is obtained.

2.2 Thermodynamic analysis

Energy is a fundamental concept of thermodynamics and one of the most significant aspects of engineering analysis. It is crucial to know the maximum possible performance of the blended fuel modes which can provide vital comparison parameters with base engine. In addition, impact of process changes such as, load and bio-fuel etc in the system in terms of system losses is also to be assessed. These findings will help in reducing the available energy loss to improve the overall engine performance.Towards this, this chapter discusses both the energy and exergy balance of the diesel and blended fuel operations. Initially, the first law analysis is presented for both the diesel and blended fuel modes.

Importance of Exergy Analysis

Quantative evaluation of energy in a cycle or in a process can be done using the first law of thermodynamics. The direction of flow of heat or work is known from the second law of thermodynamics. However, it is equally important to assign the quality to the energy. Energy can be broadly classified into high grade and low grade energy. Thus both the first and the second law of thermodynamics are to be considered for analysis.Low grade energy such as heat due to combustion, fission, fusion reactions as well as internal energies are highly random in nature. Conversion of such form of energy into high grade energy (Q→W) is of interest. This is due to the high quality of organised form of energy obtained from low quality energy. Second law of thermodynamics dictates that conversion of 100% heat into work is never possible. That part of low grade energy which is available for conversion is termed as available energy, availability or exergy. The part, which according to the second law of thermodynamics, must be rejected is known as unavailable energy. Exergy analysis helps in finding the following:

1. It can be used to determine the type, location and magnitude of energy losses in a system
2. It can be used to find means to reduce losses to make the energy system more efficient

At this point, it is worth mentioning that the environment plays an important role in evaluating the exergy.

2.2.1 First Law Analysis

The energy input in any IC engine is contained in its fuel. This amount of input energy is then converted into other forms. In an engine, the input chemical energy of fuel is usually converted to the following forms

i. Useful work output or shaft energy (Pshaft)
ii. Energy transferred to the cooling water (Qcw)
iii. Energy transferred to the exhaust gas (Qeg)
iv. Uncounted loss (Qun) due to friction, radiation, heat transfer to surroundings,operating auxiliary equipment, etc

The amount of each of these energies stated above evaluated on the basis of the firstlaw of thermodynamics is now described.

The input energy (Qin) to the diesel engine is the amount of fuel energy content in the supplied fuel and is given by,

- Qin = mf * LHV Kw

The energy converted to shaft power (Pshaft)

- Pshaft = 2 *π*N*W*r kW

The heat loss from the engine block to the cooling water is given by,

- Qcw = Mw*Cpw * (ΔT) kW

The energy wasted in form of exhaust gas losses in evaluated by,

- Qeg = Meg*Cpg* (Δt) kW

The amount of the uncounted losses is determined by performing an energy balance and given by,

- Qun = [Qin-(Pshaft+ Qcw + Qeg)] kW

2.2.2 Second Law Analysis

The knowledge of 'how the energy is lost' will help in finding means to reduce the same to improve the performance of the engine in terms of efficiency and power output. The second law analysis indicates various forms of energy that have different levels of ability to do useful mechanical work. This ability to perform useful mechanical work is defined as availability. In an IC engine, the availability input (Ain) which contained in its chemical availability of fuel is converted into other exergy forms.
In an engine, the input fuel availability is converted into the following forms:

i. Chemical availability of fuel or input availability,
- Ain = [1.0338*mf * LHV] kW

ii. Shaft availability,
- Ashaft = ∫(p-p0) * (dv/d ·) kW

iii. Availability transferred to cooling water (Acw),
- Acw=Qcw-(mw)*Cpw*T0*ln(T2/T1) kW

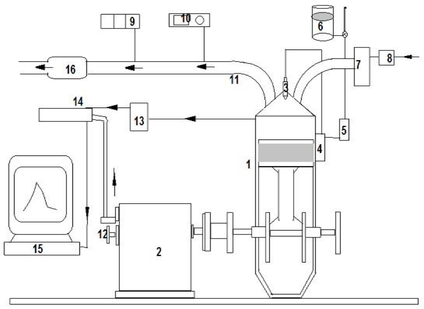
iv. Availability transferred to exhaust gases (Aeg),
- Aeg=Qeg+[(meg)*T0*(Cpg ln(T0/T5)- Reg * ln(P0/Peg))]kW

v. Destroyed availability,
- Ades = [Ain –(Ashaft + A cw + Aeg)] kW

The exergy efficiency (ɳII) is the ratio of total availability recovered from the system to the total availability input into the system. The recovered availability includes Ashaft, A cw
and Aeg. Therefore,

- ɳII =1-(Ades / Ain)

III. EXPERIMENTAL SETUP



1.kirloskar TV1 engine
2.Eddy current dynamometer
3.Injector
4. Fuel pump
5.Fuel filter
6.Fuel tank
7.Air stabilizing tank
8.Air filter
9. AVL smoke meter
10.AVL Di-gas analyser
11.Pressure transducer
12.TDC Encoder
13.Charge amplifier
14.Indimeter
15. monitor
16.Exhaust silincer

Figure 1. Experimental setup

Test has been conducted on a kirloskar TV1 engine ,four stroke,single cylinder, watercooled, direct injection and naturally aspirated diesel engine with a bowl type piston combustion chamber . specification of the test engine is shown in Table

TABLE 2 Specification of tested engine

Type	Vertical, Water Cooled
Number of cylinder	1
Number of strokes	4
Rated power	3.7kW/5bhp@1500rpm
Bore (m)	0.08
Piston offset (m)	0.00002
Stroke (m)	0.11
Compresssion ratio	16.7
Speed	1500 Rev/min
Dynamometer type	Eddy current

3.1 **Experimental procedure**

To estimate the performance parameters i.e operating parameters such as engine speed, power output and fuel consumption and brake thermal efficiency for the test fuels were calculated. In the experiments were conducted with neat diesel, diesel-blend ratio of 80:20,90:10 and biodiesel ,diesel blend with dimethyl carbonate in the ratio of 17.5:80:2.5 , 15:80:5 and 5:90:5. Temperature of cooling water, exhaust gas inlet ,outlet of the engine measured to exergy analysis. In this work, RSM is employed to model and predict the response. The experimental data Was analyzed via response regression, A software mini tab (version 15.0) is used to work on the algorithm.

Explanatory variables = {% of bio diesel, % of ethanol, % of load}
Response variables = {BSFC, BTE}

IV. RESULT AND DISCUSSION

The principal model analysis was based on the analysis of variations which provides numerical information for the y value. The different models for the response were developed in terms of actual factors and the output parameters in experimental work as a function of biodiesel ,load ,dimethyl carbonate it can be expressed as

T=f(L,BD,DMC)

F or the three factors full quadratic equation was developed using response surface methodology in minitab 17 as follows

Brake specific fuel consumption (BSFC) = 0.136 + 0.1562 L(kg) +0.003(BD) – 0.019 DMC – 0.01269 L*L – 0.00005 BD*BD + 0.0019 DMC*DMC -0.00008 L*BD +0.000119 L*DMC +0.00041 BD*DMC

Carbon monoxide (CO) = 0.12365 + 0.00720 L – 0.00679 BD – 0.02133 DMC – 0.000053 L*L +0.000330 BD*BD +0.00465 DMC*DMC 0.000114 L*BD =0.000071 L*DMC + 0.000020 BD*DMC

Carbondioxide (CO_2) = 1.717 + 0.4651 L + 0.0252 BD -0.045 DMC – 0.01039 L*L – 0.00106 BD*BD + 0.0079 DMC*DMC + 0.0017 L*BD + 0.00324 L*DMC + 0.00089 BD*DMC

Oxides of nitrogen (NO_X) = 209.6 + 16.30 L + 0.119 BD - 5.66 DMC + 0.648 L*L + 0.035 BD*BD + 1.48 DMC*DMC + 0.047 L*BD +0.181 L*DMC – 0.370 BD*DMC

Hydrocarbon (HC) = 82.9 + 6.26 L + 0.15 BD + 3.91 DMC + 0.311 L*L + 0.0180 BD*BD + 0.29 DMC *DMC – 0.0209 L*BD – 0.086 L*DMC + 0.096 BD*DMC

Table 3 Optimization criteria

Response	Goal	Lower	Target	Upper	Weight
BTE (%)	Maximize	0	31.80	-	1
BSFC	Minimize	-	0	0.9333	1
CO (%)	Minimize	-	0.090	0.230	1
CO_2(%)	Maximize	1.8	6.4	-	1
NO_X(ppm)	Minimize	-	198	538	1
HC (ppm)	minimize	-	79	194	1

4.1 Performance characteristics

BSFC is the ratio between mass fuel consumption and effective power. The engine BSFC for all the biodiesel samples produced and tested.,decreases with the increase of engine loads. The differences of BSFC between samples as well as pure diesel are very small at different engine loads for the biodiesel blends. In case of dimethyl carbonate blend (B17.5D80DMC2.5) there is an increase in BSFC ranging from 0.923 kg/KWhr to o.323 kg/KWhr from no load to maximum load respectively. This is due to lower calorific value content of biodiesel whereas the pure diesel shoes a value of 0.862kg/KWhr. When load is increased from 3 to 9 kg, the values are very close to that of the diesel. It is very clear that there is normal consumption of fuel. This is a positive sign that this alternate fuel has the capability to replace the petroleum – based diesel fuel. The lowest BSFCs region in relation to the highest BTEs, when both of the contours plots are compared, it is clearly shown that BTEs increased with the decrease of BSFCs. When figure 5.2 is considered, BTEs significantly decreased with the increase in presence of bael biodiesel in the ternary blends. In case of the dimethyl carbonate blend (B15D80DMC5) shows very close to pure diesel brake thermal efficiency . This is due to addition of DMCs which act as a catalyst to accelerate the burning rate which results decrease in ignition delay and thus increase in performance

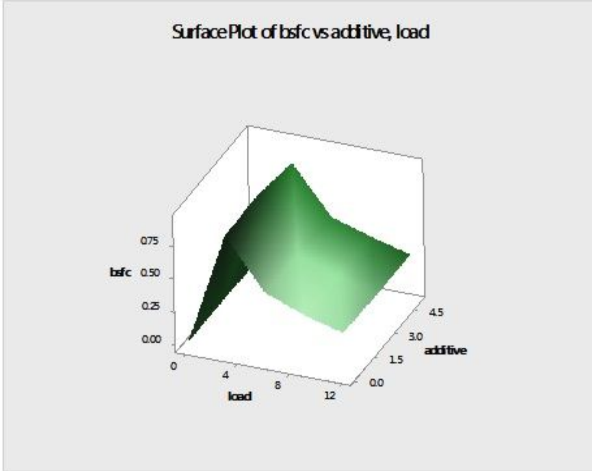


Figure 2. bsfc vs load and additive

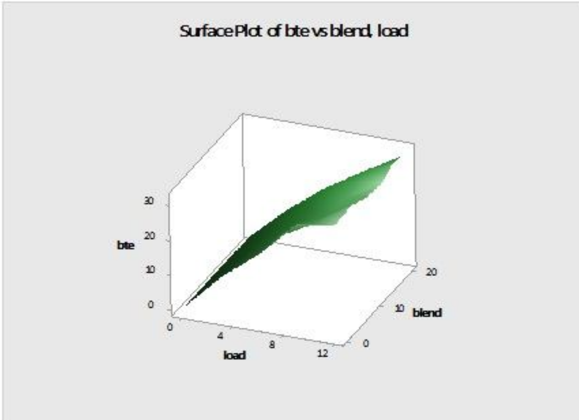


Figure 3. bte vs load and blend

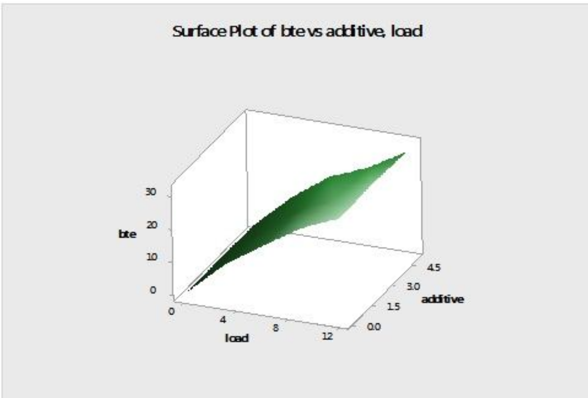


Figure 4 bte vs load and additive

4.2 Emission characteristics

The increase in ignition delay and slow burning at low engine loads originating from the use of Bael biodiesel impair the oxidation of groundnut oil with air. When the BMEP is increased and the cylinder temperature rises, thus improving the combustion and leading to lower CO emissions.

The dimethyl carbonate additive blend (B15D80DMC5) Shows lower CO emissions and it is due to increase in cylinder pressure and thus it is leads to complete oxitation of fuel and releases to CO_2.

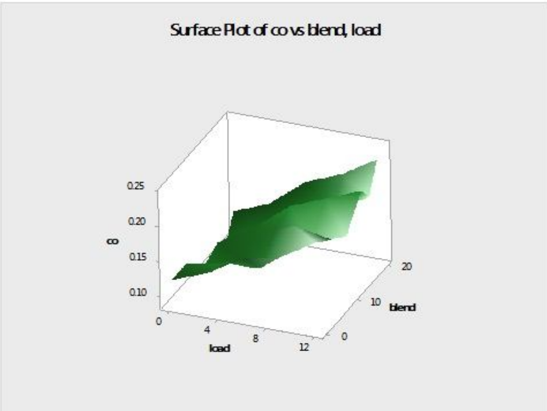


Figure 5. co vs load and blend

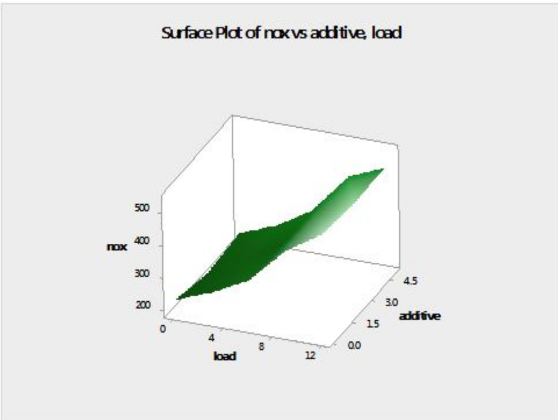


Figure 6.no_x vs load and additive

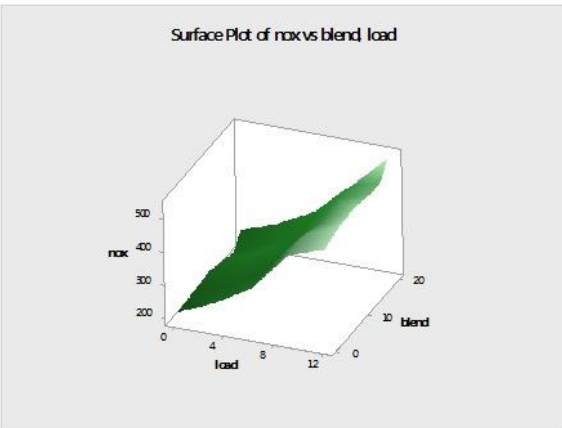


Figure 7.no_x vs load and blend

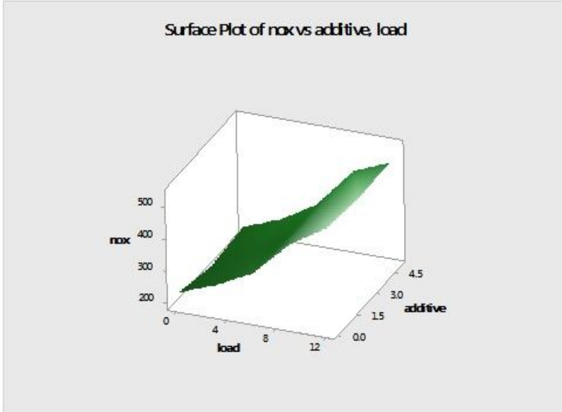


Figure 8. no_x vs load and additive

NOx emission was lower for the lower and medium engine loads. But in case of higher loads NOx emissions was observed higher for higher engine loads due to higher combustion temperature, the residence time of nitrogen at that temperature and the presence of rich oxygen regions in the combustion chamber. In addition of DMC in fuel blends the NOx emission has been slightly lower compared to blended fuel without DMC. Both the lowering combustion temperature and extending ignition delay, as well as low, heating value and high latent heat of evaporation constitute a combined effect for diminishing the NOx emission with the use of DMC.

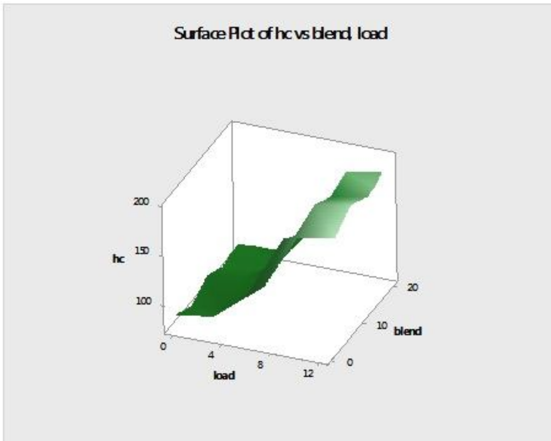


Figure 10. hc vs blend and load

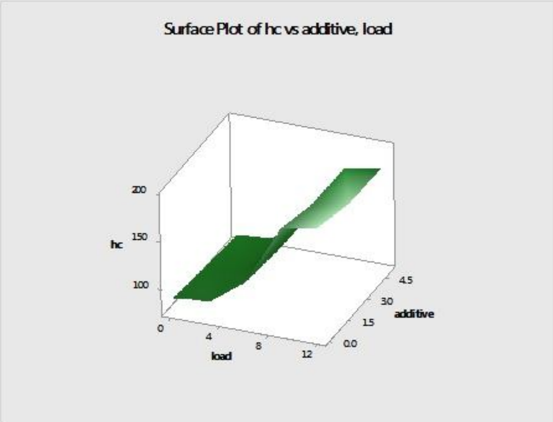


Figure 9. hc vs load and additive

4.3 EXERGY ANALYSIS

Tested fuels seem to have higher energy content than diesel fuel, however, at lower loads of 20-40%, all the tested blended fuel operations required higher fuel exergy input as compared to diesel mode. This is because of their poor combustion characteristics in the low temperature environment. As the load increased, the differences in fuel exergy input reduced under blend fuel modes as opposed to diesel mode for their improved combustion.

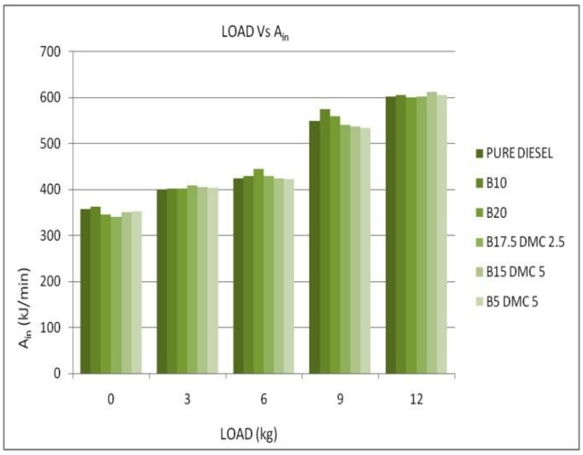


Figure 11. availability input vs load

The maximum exhaust gas lost is observed as 17.8% at 100% load. This is due to the incomplete combustion of fuel at higher temperature zone. Due to these huge availability losses through exhaust gas, the efficiencies of blend fuel operations are lower than that of diesel mode.

Availability distribution on the basis of kJ/min of available energy input to the diesel and blended fuel operations. When load is raised to maintain a higher power output at higher loads, the supply of fuel chemical energy in to the engine cylinder is increased. In the process, at elevated engine loads, the shaft availability is calculated against the amount fuel exergy input. The quantity of fuel exergy input for the engine operation at a given load mostly depends on the energy content of the fuel type and effective combustion of the fuel-air mixture. At low loads of 20% and 40%, poor combustion of DMC blend fuels causes less cooling water and exhaust gas availabilities i.e., higher destroyed availability. The destroyed availability was found minimum at the maximum efficiency condition of 80% engine load.

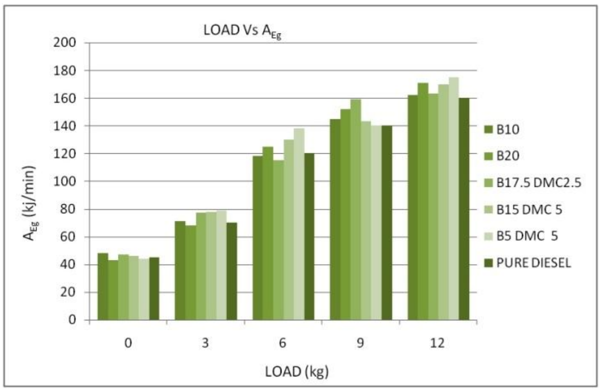


Figure 12. availability exhaust vs load

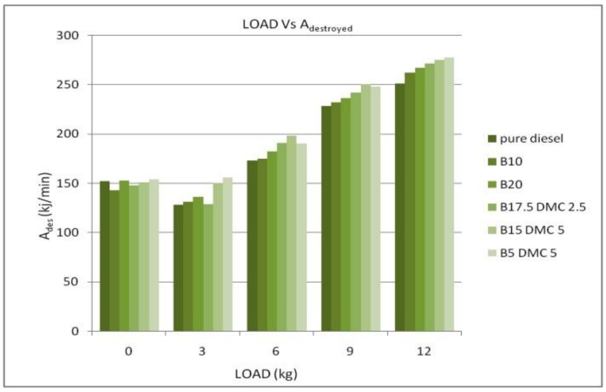


Figure 13. availability destroyed vs load

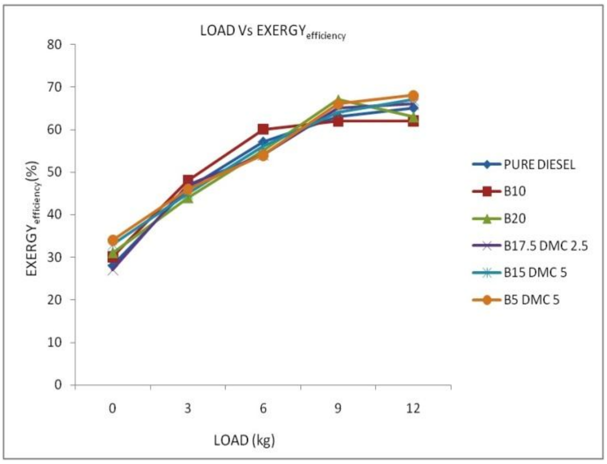


Figure 14. exergy efficiency vs load

The availability results showed that, as the load increased, the blended fuel operations generated more increase in the cumulative exhaust gas and cooling water availabilities. This allowed the more of the availability accessible for conversion to work availability. The increase in the gross work output availability increased the corresponding exergy efficiency.

V. CONCLUSION

In the present study, RSM was used to investigate the optimum blend ratios of diesel,bael biodiesel and DMC in ternary blend for the wide of operations of diesel engine. RSM powered to a powerful tool for the optimization of biodiesel blends while used as fuel in diesel engine.

Mathematical models used in this study also enable users to perform predictions for unexperimented factor levels. The regression equations developed for BTE, BSFC, CO, NO_X, and HC were found to be statistically significant. For the optimization process BSFC, CO NO_X, and HC were selected as a desirable response for minimization. The solutions are closer to the optimization criteria. Which were obtained by the desirability approach. The approach was validated for the optimization solutions by confirmatory experiments. In the results from the RSM, the error in prediction was found less than 5 %

REFERANCE

[1] Krishnamoorthi, M.; Malayalamurthi, R. Experimental investigation on performance, emission behavior and exergy analysis of a variable compression ratio engine fueled with diesel- aegle-marmoles oil-diethyl ether blends. Energy 2017, 128, 312−328.

[2] Rajesh Kumar, B.; Saravanan, S.; Rana, D.; Nagendran, A. Combined effect of injection timing and exhaust gas recirculation (EGR) on performance and emissions of a DI diesel engine fuelled with next-generation advanced biofuels diesel blends using response surface methodology. Energy Convers. Manage. 2016, 123, 470−486.

[3] Datta Bharadwaz, Y.; Govinda Rao, B.; Dharma Rao, V.; Anusha, C. Improvement of biodiesel methanol blends performance in a variable compression ratio engine using response surface methodology. Alexandria Eng. J. 2016, 55 (2), 1201−1209.

[4] Abuhabaya, A.; Fieldhouse, J.; Brown, D. The effects of using biodiesel on CI (compression ignition) engine and optimization of its production by using response surface methodology. Energy 2013, 59, 56−62

[5] Hirkude, J.; Padalkar, A.; Vedartham, D. Investigations on the effect of waste fried oil methyl ester blends and load on performance and smoke opacity of diesel of diesel engine using response surface methodology. Energy Procedia 2014, 54, 606−614.

[6] Dhanamurugan, A.; Subramanian, R. Performance of single cylinder diesel engine with bael seed biodiesel. Appl. Mech. Mater. 2014, 592−594, 1714−1718.

[7] Lahane, S.; Subramanian, K. A. Impact of nozzle holes configuration on fuel spray, wall impingement and NOx emission of a diesel engine for biodiesel-diesel blend (B20). Appl. Therm. Eng. 2014, 64 (1−2), 307−314.

[8] Dhanamurugan and R.Subramaniam, Emission and performance characteristics of a diesel engine operating on Diesel-Bael (Aeglemarmelos) Biodiesel blends, Nature Environment and Pollution technology, ISSN : 0972-6268, VOL 14, NO 2, PP 331-336, 2015

[9] Sai Ram vajja, R B V Murali Performance evaluation of Diesel engine with preheated biodiesel with additives, IOP Conf series: Material science and engineering 149 (2016)01220

[10] A R Shirineshan, M Almassi, B Ghobadian, G H Najafi, Investigating the effect of biodiesel from waste cooking oil and engine operating conditions on the diesel engine performance by Response surface methodology. IJST Transactions of mechanical engineering, vol 38, No M2, pp 289-301

[11] Y V Hanumantha Rao, Ram sudheervoleti, A V SitaramaRaju, P Nageswara Reddy, Experimental investigations on jatropa biodiesel and additives in diesel engine, Indian journal of science and technology, vol2, no 4, ISSN : 0974-6846

[12] Nikul K Patel, Padamanabhi S Nagar, Shailesh N Shah, Identification of non-edible seeds as potential feedstocks for the production and application of bio diesel, Energy and Power, 2013, 3(4):67-78

[13] L Davis Clements, Blending rules for formulating bio diesel fuel, Professor, biological systems engineering, university of Nebraska, Lincoln, NE 68583-0726

[14] K Sridhar, K ArunBalasubramiam, V Pavendan, B Ashok kumar, Experimental investigations on mixing of two bio-diesel blended with diesel as alternative fuel for diesel engine, Journal of king saud university- Engineering sciences (2017) 29,50-56

[15] Sandip S Jawre , Amit Bhagat, Sachin M Moghe, Vikram A Pakhale, Diethyl ether as additive and its effect on diesel engine performance , Global Research and development journal for engineering, vol 1, Issue 5, april 2016 . ISSN: 2455-5703

[16] A Dhanmurugan and R Subramanian, Efffect of injection timing on a diesel engine fueled with bael biodiesel, Journal of scientific and industrial research, vol 74, april 2015, pp 232-235

[17] R J Zhu, X B Wang, H Y Miao and Z H Huanj, Ultra-low emission diesel engine fuelled with Dimethoxy methane-diesel fuel blends, proc.IMechE Vol.223 Part D: J.Automobile engineering

[18] G D Zhang, H Liu, X X Xia, W G Zhang and J H Fang, Effects of Dimethyl carbonate fuel additive on diesel engine performances, proc.IMechE Vol.219 Part D: J.Automobile engineering

[19] ViveksinghShekhawat, Ravi Shankar Padwa, Role of additives and their influence on performance of engine for petroleum diesel fuel, oxygenated-diesel blends, ijert issn:2278-0181, vol 4, Issue 7, july 2015

[20] AlirezaValipour, A Review on effect of fuel additives on combustion, performance and emission characteristics of diesel and biodiesel fuel engines, IJAIEM ISSN: 2, 319-4847, VOL 3, Issue 1, Jan 2014