Performance evaluation of CI engine using diesel, diesel-biodiesel blends and diesel-kerosene blends through exergy analysis

Shruti Srivastava¹*, Harsha Chaubey¹, Yusuf Parvez¹

¹Indira Gandhi Delhi Technical University for Women, New Delhi, India
* Corresponding author. Tel: +91-8505875182, E-mail: shruti023btmae16@igdtuw.ac.in

Abstract. Conventional fuels like diesel and petroleum have been the main sources of energy for several years. The increasing demand for energy has put pressure on the usage of these fuels, resulting in much higher depletion rates over the last few years rendering the search for alternative sources of energy as the utmost priority. Attempts are being made to find suitable fuel which when blended with these commercial fuels offers same or improved engine performance and efficiency with fewer losses. Biodiesel is among those alternatives. In this paper, exergy analysis of a single cylinder diesel engine, which is water-cooled, having a rating of 5HP has been done. Biodiesel and kerosene have been blended with pure diesel and a comparative exergy analysis is done between pure diesel and all the blends. Dead state analysis has been performed for B20 (20% biodiesel and 80% diesel by volume) and K40 (40% kerosene and 60% diesel by volume). Exergy of exhaust gases decreased slightly on increasing load for all the blends and pure diesel except for K30, for which it is observed to be maximum at 20% load. Second law efficiency is increasing with an increase in applied load for all the diesel-biodiesel and diesel-kerosene blends. Dead state temperature is varied from 273K to 323K, exhaust availability decreased by 218.948 kJ for B20 and by 450.489 kJ for K40. The irreversibility increased by 218.948 kJ for B20 and by 1410.712 kJ for K40 when the energy at exhaust is kept constant. However, in actual analysis energy in exhaust changes with dead state temperature, in this case, the irreversibility decreased by 920.302 kJ for B20 and by 1690.203 kJ for K40.

Keywords: Engine, Diesel, Biodiesel, Kerosene, Combustion, Exergy analysis, Dead State Analysis.

1. Introduction

In the present scenario, energy has become imperative to human life for sustainable growth. Though it cannot be created but can be converted into another form. More effective the method of conversion, lesser is the loss of energy and higher is the efficiency. The conventional fuels are depleting very fast which has forced consumers to switch towards alternative sources of energy. Biodiesel is a suitable alternative fuel for diesel engine. From energy point of view, biodiesel has satisfied the basic criteria of the diesel engine and is recommended by the researchers for the commercial applications. The first law efficiency is not enough to do the complete analysis of an engine. It only gives a quantitative analysis of the engine. Whereas, second law efficiency does a qualitative analysis based on concept of entropy.
generation. Therefore, second law analysis is essential to check the actual performance of the system. Various articles have been published in the literature which explores the energy as well as exergy analyses of the system. Energy analysis is based on the law of conservation of energy used in evaluating performance of a system but this analysis does not give the exact scenario of the system performance. When we do an in-depth and actual analysis of an energy system, second law or exergy analysis is necessary and for that a reference environmental state is required, i.e., the dead state. Variation in dead state temperatures and pressures is also one of the parameters to evaluate performance and availability of a system along with the fuel blends and percentage variation in loads. In the research conducted by Panigrahi N et al [1] on a diesel engine with blends of Mahua oil methyl ester and diesel as engine fuels, it was observed that input energy of fuel and the exhaust gas energy increased by 6.25% and 11.86% for B20 (80% diesel by volume and 20% MOME) than diesel. Also, the efficiency was higher in case of B20 than that of diesel. B20 blend of Mahua showed similar energetic performance to diesel hence was concluded to be a suitable substitute for diesel. Cetane no. of biodiesel is higher than diesel fuel. It offers low sulphur content, higher flash point, high biodegradability, better lubricity and overall lower exhaust emissions. It is relatively clean, reduces unburned hydrocarbons, CO and particulate matter. It is observed that ignition quality is improved on blending it with diesel but higher viscosity and surface tension cause poor atomization due to increase in droplet size in case of biodiesel. Higher viscosity, cold starting and increased NOx emissions were other problems encountered. Similar experimental investigation is performed by M. Vijay K et al [2] using MME (Mahua Methyl ester) biodiesel and pure diesel blend.

Hoseinpour M et al [3] studied the effect of gasoline fumigation on the energy and exergy balance of DI diesel fuel engine with diesel and cooking biodiesel blend (B20). It was concluded that combination of B20 and gasoline fumigation under higher load has better exergy efficiency and reduction in losses was also observed.

Aghbashlo M et al [4] conducted exergoeconomic analysis of DI diesel engine using B5 (diesel-biodiesel blend) as its fuel, by using aqueous cerium oxide nanoparticles to improve combustion. B5W3 was found as an environment efficient fuel with best exergetics performance among all the blends. Jafarmadar S et al [5] performed exergy analysis of combustion of diesel/biodiesel blends in a homogenous charge compression ignition (HCCI) engine using the three-dimensional model. Exergy efficiency was increased by 4.9% and 5.7% when biodiesel percentage was increased from 0% to 20% and 50% respectively. Khoobbakht G et al [6] used diesel, ethanol and biodiesel, fuel blends in a DI Diesel engine to perform exergy and energy analysis of combustion. It was observed exergetic efficiency increased by increasing engine load, speed and increased concentration of biodiesel and bioethanol. Paul A et al [7] conducted experimental study to find combustion, emission, exergy characteristics of a CI engine using diesel-ethanol-biodiesel blends to evaluate its performance. The blend D3E15B50 with 15% ethanol showed best exergetic performance with 22.02% reduction in exergy destruction rate and 21.06% reduction in entropy generation rate, indicating higher sustainability prospect. Noorollahi Y et al [8] studied the effect of different diesterol (diesel- biodiesel- ethanol) blends on engine performance and exhaust gases. It was observed that the blend D91B6E3 has the best efficiency, performance and emission. Patel H K and Kumar S [9] did performance analysis of diesel engine using mixture of diesel/bio-diesel and aluminium oxide nano particle additive. Better results were observed in case of fuel containing aluminium oxide nano particles because the additive improved combustion characteristics and degree of mixing. Kanoglu M et al [10] evaluated heat and work interactions, efficiency and exergy losses in various components of power plant using energy and exergy concepts. The results were used as a basis for evaluation of performance, design and analysis of diesel engine power units.

Cetane no of kerosene is lower compared to biodiesel. It also has lower density, viscosity and distillation temperature [11]. The primary reason of blending kerosene with diesel fuel is to improve cold flow operability which is a problem in colder regions. Ziegler K L and Manka J S [12] observed that kerosene simply dilutes the paraffin waxes present in diesel fuel and improves its cold flow characteristics. Apart
from diesel, kerosene when blended with biodiesel showed better injection characteristics and lower NOx emissions for all loads as per the research work of Ayudin H [13].

Dwivedi G et al [14] used waste cooking biodiesel and its blend with kerosene and ethanol to study performance of engine. Waste cooking biodiesel with kerosene and ethanol was recommended for cold climatic conditions due to improved cold flow property and WCB was found to be best alternative to diesel.

Ameer Uddin S M et al [15] analysed the performance of diesel engine with mustard- kerosene blends. It was concluded that mustard oil when blended with 20% -30% kerosene could substitute diesel since only a slight reduction was observed in power and efficiency compared to diesel. The research conducted by Aydin H et al [16] on emissions from using biodiesel- kerosene blends as its fuel, showed that 20% blend of kerosene with 80% biodiesel have better fuel volatility and ignitionability. Emissions were low, engine power increased and specific fuel consumption decreased.

Patil K R and Thipse S S [17] did experimental investigation on combustion, performance and emissions of CI Engine using Diethyl ether (DEE)- kerosene- diesel blends with increased concentration of DEE. DEE diesel blends showed less NOx emissions. The optimum blend ratio was found to be DE15D. DEE blends showed higher cetane number and oxygen content when concentration of DEE is increased in blends. Abusoglu A and Kanoglu M [18-19] studied energy, exergy and exergoeconomic analysis of diesel engine power cogeneration (part 1), and did the actual cogeneration power plant study based on application of the formulation developed, (part 2). Exergy and energy methods were implemented on each system component and subsystem to yield exergy efficiency and destruction. A detailed cost analysis was done afterwards for optimum market price. Caliskan H et al [20] did performance assessment of an IC engine by varying dead state temperatures. It was observed as the dead temperature increased, exergetic efficiencies decreased. Caliskan H et al [21] performed exergy and energy analysis using soybean oil methyl ester (SME) and high oleic soybean of methyl ester (HOME). Energy efficiency, exergy efficiency, energy losses and exergy destructions were compared between fuels. No statistical differences in fuels were observed.

In present study, exergy analysis of diesel engine has been done using diesel-biodiesel blend, diesel-kerosene blend and pure diesel as fuel. The biodiesel used in the experiment is prepared in laboratory using Jatropha seeds. Due to its high production rate and minimum water supply requirement, jatropha is one of the most attractive resources of biodiesel production in India [22]. A detailed comparative investigation is carried out for blends by varying engine load. Analysis of availability and irreversibility rates at different dead state temperatures has also been done.

2. Properties

2.1 Biodiesel

The following properties of biodiesel, which were measured in the laboratory, are listed below.

| S. N. | Property of the fuel | Value       |
|------|---------------------|-------------|
| 1    | Density             | 886.34 kg/m³ |
| 2    | Kinematic Viscosity | 5.05 x 10^-6 m²/sec |
| 3    | Net Calorific Value | 38.829 MJ/kg  |
2.2 Diesel

Some important properties of diesel fuel which have been used for experiment are mentioned below in Table II.

| Table II. Various properties of diesel [23] |
|--------------------------------------------|
| S. N. | Property                   | Value            |
|-------|----------------------------|------------------|
| 1     | Density                    | 825.6 kg/m³      |
| 2     | Kinematic Viscosity        | 4.0 x 10^-6 m²/sec |
| 3     | Net Calorific Value        | 42.6 MJ/kg       |

2.3 Kerosene

Some important properties of kerosene fuel are listed below in Table III.

| Table III. Various properties of kerosene [24] |
|-----------------------------------------------|
| S. N. | Property                 | Value            |
|-------|--------------------------|------------------|
| 1     | Density                  | 810 kg/m³        |
| 2     | Kinematic Viscosity      | 2.71 x 10^-6 m²/sec |
| 3     | Net Calorific Value      | 43 MJ/kg         |

2.4 Diesel-Biodiesel Blends

Four different blends of diesel and biodiesel have been prepared. The following fuel blends such as B10, B20, B30 and B40 are taken for the experiments. The blends are prepared in such a way that 10 ml of biodiesel and 90 ml diesel are kept in a sample of 100 ml for B10. Similarly, other blends such as B20, B30 and B40 have been prepared. The prepared blends are mentioned in Figure 1.

2.5 Diesel-Kerosene Blends

Four blends of kerosene and diesel such as K10, K20, K30 and K40 have been used in experiment. The blends are prepared on volume basis in the same pattern as in the case of diesel-biodiesel blends. The prepared blends are mentioned in Figure 2.
3. Experimentation on Setup

**Engine Setup**

The setup used for experiment consists of a 4-stroke, single cylinder, water cooled diesel engine. For evaluation of mass flow rate of exhaust gases, a calorimeter (counter flow heat exchanger type) is installed at the exhaust. Load is applied on the engine by a Brake Dynamometer. In order to calculate mass flow rate of air, an orifice meter is installed at the supply line of air. Water is taken as the working fluid for both the calorimeter and cooling system. To measure the mass flow rate of fuel, a burette is attached with the fuel tank. A line diagram for this setup is shown in Figure 3.

![Figure 3. Line Diagram of Setup](image)

![Figure 4. Photograph of the Engine Setup](image)

| **Table IV. Engine Specifications** |
|-------------------------------------|
| **Name**               | **Details**                                      |
| Made by                | Eicher (5 HP)                                   |
| Loading Device used   | Belt type Brake Dynamometer                     |
| Engine type            | Single cylinder 4-stroke water cooled Diesel Engine |
| Rated speed and Rated Power | 1500 rpm and 3.73 kW                     |
| Stroke Length/ Cylinder bore | 110 mm/80 mm                                |
| Swept Volume           | 553 cc                                          |
4. Experimental Test Procedure

Experiments are conducted using diesel-biodiesel and diesel-kerosene blends at various loading conditions. The eight blends prepared - B10, B20, B30 and B40 and K10, K20, K30, K40 along with pure diesel are used. The observations for exergy analysis have been taken from earlier experimental investigation using the same blends [23-24].

Availabilities of fuel, shaft, cooling water and exhaust have been calculated which are used to find availability of unaccounted losses. Actual performance characteristics have been analysed and compared with engine fuelled with pure diesel. Variation in availability rates and irreversibility rates at exhaust has been analysed by changing dead state temperatures.

5. Formulation and Exergy Analysis

5.1 Exergy Balance:
Exergy of the system is maximum useful work obtained from a system when the system comes in thermodynamic equilibrium with the dead state. Concept of exergy is used to perform exergy balance for analysis of thermal systems. Both energy and exergy balance are similar concepts with only one fundamental difference that energy balance is based on the law of conservation of energy whereas exergy balance is based on law of degradation of energy [25]. Exergy balance for engine gives availability of fuel energy being utilized in shaft, water cooling, exhaust and unaccounted losses occurred.

The first component into which exergy is divided is physical exergy [26,27]. The expression for specific physical exergy of an ideal gas as stated in Kotas [28] is given by the equation (1).

$$E_{ph} = C_p(T - T_0) - T_0(C_p \ln \frac{T}{T_0} - R \ln \frac{P}{P_0})$$  \hspace{1cm} (1)

Where \(T_0\) and \(P_0\) are temperature and pressure at ambient conditions and \(C_p\) is specific heat of gas at constant pressure.

The two components of flow exergy of fuel used are thermomechanical and chemical exergy. The thermomechanical exergy of the fuel is zero. To evaluate chemical exergy of the liquid fuel the equation (2) stated in Kotas [28] is used:

$$E_{ch} = [LHV \left\{1.0401 + 0.1728\left(\frac{H}{C}\right) + 0.0432\left(\frac{O}{C}\right) + 0.2169\left(\frac{S}{C}\right) \ast \left(1 - 2.0628\left(\frac{H}{C}\right)\right)\right]\]$$  \hspace{1cm} (2)

In the above equation (2), LHV is lower calorific value of the fuel. H, C, S and O are taken as mass fraction of hydrogen, carbon, sulphur and oxygen respectively.

Chemical exergy associated with the exhaust gas is calculated according to the formula mentioned in equation (3).

$$E_{ch} = \sum_{i=1}^{n} a_i \ln \left(\frac{Y_i}{Y_{e_i}}\right)$$  \hspace{1cm} (3)
where $Y_i$ is the molar ratio of their respective component in the exhaust gas and $Y_e$ the molar ratio of their respective component in the reference environment.

The availability of fuel, cooling water, exhaust gases leaving the engine is calculated for diesel, diesel-biodiesel blends and diesel-kerosene blends. Further, availability of unaccounted losses is calculated. Ambient temperature and pressure for the experiment were taken as 298.15 K and 1 atm respectively. By comparison, it was found that N$_2$ is the main component of diesel exhaust gas (similar to ambient air), as its concentration is much higher than that of other elements and pollutants. Hence, for approximation, air properties are used for diesel exhaust gas calculations [29].

5.2 Availability of fuel in kW ($A_f$):

The availability of liquid fuels is calculated by equation (2).

5.3 Availability of shaft in kW ($A_s$):

Since work is high-grade energy therefore brake power of the engine is considered as exergy.

5.4 Availability of cooling water in kW ($A_w$):

$$A_w = Q_w - m_w C T_0 \ln \frac{T_2}{T_1}$$

(4)

Where $T_0$ is ambient temperature, $T_2$ and $T_1$ are inlet and outlet temperatures of water jacket, $m_w$ is water mass flow rate and $C$ is the specific heat of water.

5.5 Availability of exhaust gases in kW ($A_e$):

$$A_e = Q_e - \left[ m_e T_0 \left( C_p \ln \frac{T_4}{T_0} - R \ln \frac{P_4}{P_0} \right) \right]$$

(5)

Where $m_e$ is mass flow rate of exhaust gases, $C_p$ is specific heat at constant pressure for exhaust gases, $T_4$ is exhaust gas to calorimeter inlet temperature and $P_4$ is final pressure.

5.6 Availability of unaccounted losses in kW ($A_{un}$):

$$A_{in} = A_e + A_w + A_e + A_{un}$$

$$A_{un} = A_{in} - A_s - A_w - A_e$$

(6)

5.7 Second Law Efficiency

$$E = \frac{A_s}{A_f} \times 100$$

(7)

5.8 Dead State Analysis

Evaluation of exergy is done with respect to a dead state (reference environment) [30]. The blends that showed best exergetic performances are taken for dead state analysis. Dead state temperatures have been varied, availabilities, irreversibility and efficiencies are noted down for various loads. After making comparisons, the dead state temperature which showed maximum efficiency for both the blends is determined. Pattern of change in efficiency with variation in dead state temperatures is observed.
6. Results and Discussions

The research has been conducted on single cylinder 4 stroke diesel engine. Various parameters like availability of fuel, shaft, cooling water, exhaust gases and unaccounted losses have been calculated for detailed study and performance analysis of the engine. Engine is made to run for 30 mins. Variation in availability and irreversibility rates with dead state temperature in case of exhaust gases have been evaluated for blends having best energetic performance. Comparison between blends and pure diesel has been drawn. A detailed study has been done to find the areas of maximum losses. Exergy analysis is performed using second law of thermodynamics or law of degradation of energy. Graphs have been plotted to understand the analysis more clearly with ease.

![Figure 5. Load Vs Exergy (B0)](image)

![Figure 6. Load Vs Exergy (B10)](image)

![Figure 7. Load Vs Exergy(B20)](image)

![Figure 8. Load Vs Exergy(B30)](image)
Graphical analysis has been performed for pure diesel, diesel-biodiesel blends B10, B20, B30 and B40. Figure 5-9 show graphs plotted between various loads and exergies for diesel and diesel-biodiesel blends. Input fuel exergy and shaft exergy are observed to be increasing with an increase in applied load for pure diesel and all the blends. Exergy of exhaust gases is decreasing with increasing load values for B10, B20, B30, B40 and for pure diesel. For pure diesel, exhaust gas exergy continuously decreases on increasing the load whereas in case of blends it reaches to a minimum value at 20% load and slightly increases up to 60% load. There is an increase in the value of second law efficiency for all the blends as well as pure diesel on increasing the engine load.

Figure 9. Load Vs Exergy(B40)

Figure 10. Load Vs Exergy (K0)

Figure 11. Load Vs Exergy(K10)
Figure 10-14 show graphs plotted between various loads and exergies for diesel and diesel-kerosene blends. On increasing load it is observed that both input fuel exergy and shaft exergy increases for pure diesel and all the diesel-kerosene blends K10, K20, K30 and K40. Exergy of exhaust gases is decreasing slightly on increasing load for blends K10, K20, K40 and pure diesel whereas in case of K30 it is increasing and is maximum for 20% load. Second law efficiency is increasing on increasing applied load for diesel and all the blends.

As it is mentioned that the diesel fuel has cold starting problem which can be overcome by blending with kerosene, therefore kerosene blended fuel in CI engine will be more suitable for colder regions where environment temperature is low or during winter season. To check the exergetic performance of the diesel-kerosene blended fuel in CI engine, the authors have done the exergy analysis by changing the environment temperature. Environment is considered as the dead state.
Figure 15. Dead state temperature Vs Availability at Exhaust

Figure 16. Dead state temperature Vs Irreversibility at Exhaust

Figure 17. Dead state temperature vs Irreversibility at Exhaust

Figure 15 show graphs plotted between various dead state temperatures and availability at exhaust and irreversibility at exhaust for blend B20 of diesel-biodiesel blend and K40 of diesel-kerosene blend. Availability at exhaust is decreasing for both blends B20 and K40, being minimum at 323K. As dead state temperature is varied from 273K to 323K, exhaust exergy decreased by 218.948 kJ for diesel-biodiesel blend B20 and for kerosene- diesel blend it decreased by 450.489 kJ. The first analysis for irreversibility is done by keeping the energy at exhaust as constant, Figure 16, it is observed that irreversibility at exhaust for both the blends is increasing with increase in dead state temperature, being maximum for 323K. The irreversibility is increased by 218.948 kJ for diesel-biodiesel blend B20 and by 1410.712 kJ for kerosene-diesel blend K40. In actual analysis, energy in exhaust gases should also
vary with the variation in dead state temperatures. The second graphical analysis shows variation in irreversibility rates by varying dead state temperature which in turn varies energy at exhaust, Figure 17. It is observed that irreversibility at exhaust is decreasing when dead state temperature is increased 273K to 323K for both the blends B20 and K40. The irreversibility decreased by 920.302 kJ for diesel-biodiesel blend B20 and by 1690.203 kJ for kerosene-diesel blend K40.

7. Conclusions

Pure diesel, Diesel-Biodiesel blends B10, B20, B30, B40 and diesel-kerosene blends K10, K20, K30, K40 has been used in this experimental analysis. Detailed exergy analysis is done. Availability associated with the input fuel, shaft and exhaust gases along with the second law efficiency for all the blends is found out for different loads. Further, a comparative analysis has been performed. For dead state temperature analysis, blends B20 and K40 are taken, availability at exhaust and irreversibility rate at exhaust are calculated for different dead state temperatures. The main conclusions drawn from this experimental investigation and detailed study are mentioned below:

- In case of pure diesel, exergy of exhaust gases decreased slightly on increasing the load and is observed to have minimum value for 60% load whereas for blends B10, B20, B30 and B40 it has minimum value at 20% load and there is a slight increase in its value on increasing the load. Second law efficiency increases on increasing load for every diesel- biodiesel blend and pure diesel.
- In case of kerosene, it is observed that on increasing load on the engine both input fuel exergy and shaft exergy increases for pure diesel as well as for all the diesel-kerosene blends. Exergy associated with the exhaust gases is decreasing slightly on increasing load on the engine when the engine is burned with the fuel blends K10, K20, K40 and pure diesel whereas in case of K30 it is increasing and gives maximum value for 20% load. Second law efficiency is increasing with increase in applied load for diesel and all the diesel-kerosene blends.
- Blending diesel with biodiesel and kerosene decreases exergy in exhaust gases when engine is working on higher load, which implies improved combustion characteristics. Exergy in exhaust is observed to be minimum for B20 at no load condition and for K10 at 60% load condition.
- Dead state analysis is done for B20 and K40 fuel blends and the results show that for higher dead state temperatures, availability at exhaust and irreversibility at exhaust both are decreasing, having lowest value at 323K.
- Availability at exhaust is decreasing for both blends B20 and K40, being minimum at 323K. As dead state temperature is varied from 273K to 323K, exhaust exergy for B20 and K40 are decreased by 218.948 kJ and 450.489 kJ respectively.
- The irreversibility increased by 218.948 kJ for B20 and by 1410.712 kJ for K40 when energy at exhaust is kept constant. However, in actual analysis, energy in exhaust will keep changing with varying dead state temperature. It has been noticed that the irreversibility decreased by 920.302 kJ for B20 and by 1690.203 kJ for K40 with increase in dead state temperature.

References

[1] Panigrahi N, Mohanty M K, Mishra S K and Mohanty R C 2014 Performance, Emission, Energy and Exergy Analysis of a C.I Engine using Mahua Biodiesel Blends with Diesel International Scholarly Research Notices Volume 14 Article ID 207465 13 pages.

[2] Kumar M V, Babu A V and Kumar P R. 2018 Experimental investigation on the effects of diesel and mahua biodiesel blended fuel in direct injection diesel engine modified by nozzle orifice diameters Renew. Energy vol. 119 pp. 388–399.

[3] Hoseinpour M, Sadrnia H, Tabasizadeh M and Ghobadian B 2017 Energy and Exergy analyses
of diesel engine fuelled with diesel, biodiesel- diesel blend and gasoline fumigation Energy 141 2408-2420.

[4] Aghbashlo M, Tabatabaei M, Khalife E, Shojaei T R, and Dadak A 2018 Exergoeconomic analysis of a DI diesel engine fuelled with diesel/ biodiesel (B5) emulsions containing aqueous nano cerium oxide Energy 149 967-978.

[5] Jafarmadar S and Nemati P 2016 Exergy analysis of diesel/ biodiesel combustion in a homogenous charge compression ignition (HCCI) engine using three-dimensional model Renewable Energy 99 514-523.

[6] Khoobbakht G, Akram A, Karimi M and Najafi G 2016 Exergy and Energy Analysis of combustion of blended levels of biodiesel, ethanol and diesel fuel in a DI diesel engine Applied Thermal Engineering 99 720-729.

[7] Paul A, Panua R and Debroy D 2017 An Experimental study of combustion, performance, exergy and emission characteristics of a CI engine fuelled by Diesel-ethanol-biodiesel blends Energy 141 839-852.

[8] Nooroallah Y, Azadbakht M and Ghabadian B 2018 The effect of different diesterol (Diesel-Biodiesel-ethanol) blends on small air cooled diesel engine performance and its exhaust gases, Energy 142 196-200.

[9] Patel H K and Kumar S 2017 Experimental analysis on performance of diesel as a working fuel with aluminium oxide nanoparticle additive Thermal Science and Engineering Progress 4 252-258.

[10] Kanoglu M, Isik S K and Abusoglu A 2005 Performance characteristics of a diesel engine power plant, Energy Conversion and Management 46 1692–1702.

[11] Bergstrand P 2007 Effects on combustion by using kerosene or MK1 diesel p. 01e0002. SAE Paper

[12] Ziegier K L and Manka J S 2000 The effect of mixing diesel fuels blended with kerosene and cloud point depressants SAE Paper 2000-01-2884.

[13] Aydin H 2016 Scrutinizing the combustion, performance and emissions of safflower biodiesel–kerosene fuelled diesel engine used as power source for a generator Energy conversion and Management 117 400-409.

[14] Dwivedi G, Sharma M P, Verma P and Kumar P 2018 Engine Performance Using Waste Cooking biodiesel and its blends with kerosene and ethanol Materials Today: Proceedings 5 22955-22962.

[15] Uddin S M, Azad A K, Alam M, M and Ahamed J U 2015 Performance of a Diesel Engine run with Mustard–kerosene blends Procedia Engineering 105 698-704.

[16] Aydin H, Bayindir H and Ilkilic C 2011 Emissions from an Engine Fuelled with Biodiesel–Kerosene Blends Energy sources Part A 33:130-137.

[17] Patil K R and Thipse S S 2015 Experimental investigation of CI engine combustion, performance and emissions in DEE-kerosene- diesel blends of high DEE concentration Energy Conversion and Management 89 396-408.

[18] Abusoglu A and Kanoglu M February 2009 Exergetic and thermoeconomic analyses of diesel engine powered cogeneration: Part 1, Applied Thermal Engineering 29(2-3):234-241.

[19] Abusoglu A and Kanoglu M February 2009 Exergetic and thermoeconomic analyses of diesel engine powered cogeneration: Part 2, Applied Thermal Engineering 29(2-3):242-249

[20] Caliskan H, Tat M E and Hepbasli A 2009 Performance assessment of an internal combustion engine at varying dead (reference) state temperature Applied Thermal Engineering 29 3431-3436

[21] Caliskan H, Tat M E, Hepbasli A and Gerpen J V 2009 Exergy analyses of engines fuelled with biodiesel from high-oleic soybeans based on experimental values International Journal of Exergy Volume 7 Issue 1.

[22] Leduc S, Naturajan K, Dotzauer E, McCallum I and Obersteiner M 2009 Optimizing biodiesel production in India Appl Energy 86 S125–31.
[23] Choudhary P, Sachar S, Khurana T, Jain U, Parvez Y and Soni M 2018 Energy Analysis of Single Cylinder 4-Stroke Diesel Engine Using Diesel and Diesel-Biodiesel Blends International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13 Number 12 pp.10779-10788.

[24] Jain U, Khurana T, Sachar S, Choudhary P and Parvez Y September 2018 Energy Analysis of Single Cylinder 4-Stroke Diesel Engine Using Diesel and Diesel-Kerosene Blends IJRAR-International Journal of Research and Analytical Reviews (IJRAR) E-ISSN 2348 -1269 P-ISSN 2349-5138 Volume 5 Issue 3 Page No pp. 194-203.

[25] Tsatsaronis G 2006 Definitions and nomenclature in exergy analysis and exergoeconomics Energy 32 249–253 doi: 10.1016/j.energy.2006.07.002.

[26] Kotas T J September 1980 Exergy Concepts for Thermal Plant, First of two papers on exergy techniques in thermal plant analysis International Journal of Heat and Fluid Flow Volume 2 Issue 3 Pages 105-114.

[27] Kotas T J December 1980 Exergy Concepts for Thermal Plant, Second of two papers on exergy techniques in thermal plant analysis International Journal of Heat and Fluid Flow Volume 2 Issue 4 Pages 147-163.

[28] Kotas T J 1985 The Exergy Method of Thermal Plant Analysis

[29] Perry R.H. 1984. Perry’s Chemical Engineers Handbook McGraw-Hill, New York, 6th edition

[30] Moran M J 1982 Availability Analysis: A Guide to Efficiency Energy Use Prentice Hall Englewood Cliffs, NJ.