**Advances in Energy Research**, *Vol. 8, No. 4 (2022) 213-222*
https://doi.org/10.12989/eri.2022.8.4.213 

# Energy and exergy analysis of CI engine dual fuelled with linseed biodiesel and biogas

S. Lalhriatpuia* and Amit Pal[a]

*Department of Mechanical Engineering, Delhi Technology University, Delhi 110042, India*

(*Received July 20, 2022, Revised September 5, 2022, Accepted September 7, 2022*)

**Abstract.** Our overdependence on the limited supply of fossil fuel with the burden of emission as a consequence of its utilization has been a major concern. Biodiesel is emerging as a potential diesel substitution for its similar performance, with the additional benefits of emitting lesser emissions. Due to the easy availability of feedstock for Biogas production, Biogas is studied for its use in CI engines. In this study, we considered Linseed Biodiesel and Biogas to run on dual fuel mode in a CI engine. An energy and exergy analysis was conducted to study the rate of fuel energy and exergy transformation to various other processes. Exergy relocation to exhaust gases was observed to be an average of 5% more for dual fuel mode than the diesel mode, whereas exergy relocation to the diesel mode was observed to be more than the dual fuel modes. Also, exergy loss to exhaust gas is observed to be more than the exergy transferred to cooling water or shaft. The exergy efficiency observed for biodiesel-biogas mode is only lesser by 3% compared to diesel-biogas mode, suggesting Biodiesel can be a substitute fuel for diesel.

**Keywords:** biodiesel; biogas; dual fuel; efficiency; energy; exergy

## 1. Introduction

Due to the continued rise in the demand for energy over the past decades, there has been a growing concern about the availability of energy sources in the future times. Also, the emission generated via the utilization of these energy sources has been a major concern in view of how the earth is shaping up in the form of climate change (Fathi *et al*. 2020). Fossil fuels have always been the primary energy source over the last few decades. Fossil fuel demand has risen exponentially, but its non-renewability nature is considered to be a major issue in supplying the ever-increasing demand (Taqizadeh *et al.* 2020). Also, fossil fuels are the main energy source for all the automobile industries, leading to the conclusion that the major emission emitted is due to the combustion of these fossil fuels. Hence there is a need to consider researching other energy sources in the form of alternative fuels or renewable fuels(M. Rahman *et al*. 2009). Some of the alternative renewable fuels that have been researched are in form of biodiesels, bioalcohols, biogas, etc. Biodiesel due to its physiochemical properties has been heavily researched for its utilization in diesel engines, making it an attractive option to consider as a substitute fuel for diesel. Biodiesel can be obtained via processing from various sources like edible and non-edible oils, cooked oils,

*Corresponding author, Ph.D. Student, E-mail: sactrix777@gmail.com
[a]Professor, E-mail: amitpal@dce.ac.in


http://www.techno-press.org/?journal=eri&subpage=7 ISSN: 2287-6316 (Print), 2287-6324 (Online)

etc (Murugesan *et al*. 2009). Among the gaseous fuels studied over the years, biogas due to its simpler production process and easy availability of its feedstock has emerged as an attractive fuel to consider in view of replacing diesel or substituting parts of diesel consumption with biogas. Utilization of raw biogas is possible via dual fuelling in diesel engines. Dual fuelling can be beneficial for numerous reasons. One of such is its flexibility, the possibility to run an engine on diesel alone or to run on diesel added with biogas. Also since a portion of diesel gets substituted by biogas, there is a direct financial benefit (Sharma *et al*. 2020).

An IC engine may be evaluated based on performance, emission, energy, and exergy analysis. Energy and exergy are one such analysis which is conducted via the 1st and 2nd law of Thermodynamics. The 1st law suggests that energy supplied to an engine gets relocated to other various processes i.e., shaft, cooling water, exhaust gas, and uncounted loss. But the 2nd law states that irreversibility occurs along all the processes mentioned in the 1st law (López *et al.* 2014, Ramos da Costa *et al*. 2012). The useful energy that we get to use after the irreversibility factor is addressed is termed exergy. Hence an exergy analysis is useful for determining the losses placement in the system and also the quantity of those losses. Hence based on possibilities and desires, one may address those losses and prepare a more efficient exergy unit (Jafarmadar and Nemati 2016, Rosen 2006). With the benefits stated for the exergy study, it is safe to realize that better performance analysis is possible when combining both analysis. (Abbasi *et al*. 2016)

A study was made to observe the effect of changing injection pressure in the CI engine. This study came to the conclusion that with the increase in injection pressure, there was a decline in both the energy and exergy efficiency (Özkan 2015). Chemical reaction while Combustion and heat transmission was considered to be the impacting cause for irreversibility in a diesel engine (Caliskan *et al*. 2009).Cetane number and ignition delay increased resulted in an increase of exergy efficiency has also been reported for diesel engine (Tat 2011). A study on CI engine where the considered fuels were dodecane, methane, and methanol reported an observation that the destroyed exergy was found to be more in heavy fuel when compared to lighter fuels (Azoumah *et al.* 2009, Rakopoulos and Kyritsis 2001)

B20 blend of soybean oil methyl ester and yellow grease methyl ester were utilized in a CI engine with the purpose of comparing its performance and exergy analysis. The study conclude that the biodiesel blend resulted in higher brake specific fuel consumption in contrast to the diesel mode. The study also suggests that destroyed availabilities are the most significant parameter among all the other elements where the exergy of fuel relocated (Sayin *et al*. 2007). A biodiesel blend from palm and cotton was studied in a CI engine as the primary pilot fuel. The study reported that exergy studies are a critical technique for determining the maximum loads that CI engines can handle (Azoumah *et al.* 2009). A similar study for biodiesel suggests load on the engine is a factor in determining exergy(Aghbashlo *et al.* 2015). A decline in Destroyed availability with the decline in engine speed was reported for a studied conducted for use of Sunflower Biodiesel in a diesel engine (Açikkalp *et al.* 2014). Also destroyed exergy was reported to increase with an increase in the blending percentage of biodiesel with diesel( Meisami and Ajam, 2015). A similar inclination of results was reported for both energy and exergy analysis. The exergy relocated to the exhaust gas was reported to be more for dual fuel mode than the diesel mode. Also, the fuel exergy was reported more for diesel mode due to its higher heating value as compared to the dual fuel mode (Sorathia and Yadav 2012).

The research done on exergy and energy analysis of CI engines for Biodiesel is few, hence for a better understanding of the fuel utilization, there is a need for more study. Particularly the study of the use of Linseed Biodiesel in CI engine for energy and exergy study is non-existent. For our

Table 1 Physiochemical properties of fuel used

| Sl No. | Characteristics | Diesel | Linseed Biodiesel | Biogas |
|---|---|---|---|---|
| 1 | Density (kg/m3) | 840 | 865 | 1.19 |
| 2 | Flash point (oC) | 71 | 150 | - |
| 3 | Lower heating value (MJ/kg) | 43.85 | 38.6 | 21.5 |
| 4 | Cetane number | 48 | 32.7 | - |
| 5 | Kinematic Viscosity (at 40oC) | 2.92 | 6.2 | 3.55 |
| 6 | Pour point (oC) | -8 | -10 | - |

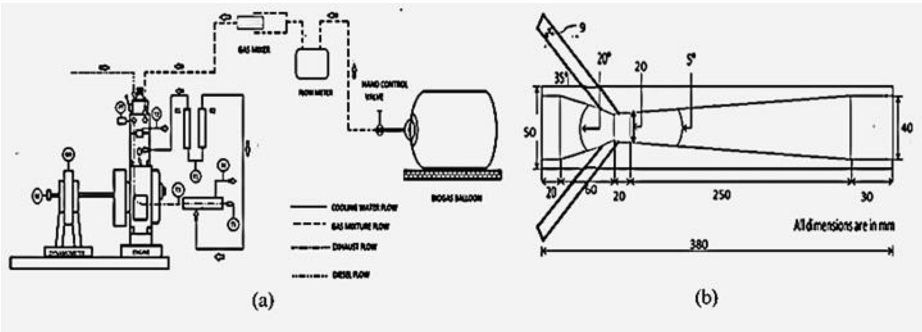



Fig. 1 Schematic diagram of (a) the experimental test setup; and (b) fuel-air mixing chamber

study, we are using Linseed Biodiesel with the addition of biogas as dual fuel. A detailed energy and exergy analysis was performed and the results are stated in the result and discussion section and a comparison was made between all the fuel modes i.e diesel or single fuel mode(D100), diesel-biogas dual fuel mode(D-DDF), linseed biodiesel-biogas dual fuel mode (LBD-DF).

## 2. Properties of the tested fuel

Biogas composition varies depending on the type of feedstock used and the production process parameter. The two main constituents are carbon dioxide and Methane. Also, there are some traces of hydrogen sulphide in its raw form. Further upgradation of biogas is possible via the different enhancement techniques available. The most common and easy method is water scrubbing for minimizing carbon dioxide and iron for removal of hydrogen sulphide. The fuel properties were measured using different ASTM testing methods. D-1298, D-93, D-240, D-4737, D-445, and D-97 were the ASTM method used for the properties mentioned below respectively.

## 3. Experimental setup and methodology

The experiment was performed on a 3.5 kW power, single cylinder, 4 stroke, constant speed diesel engine. The dynamometer type eddy current was utilized for applying load. The engine is water cooled and the measurement of its flow was achieved via rotameters. For the measurement of airflow and fuel flow, a manometer and fuel measuring unit is used. The temperature sensors are

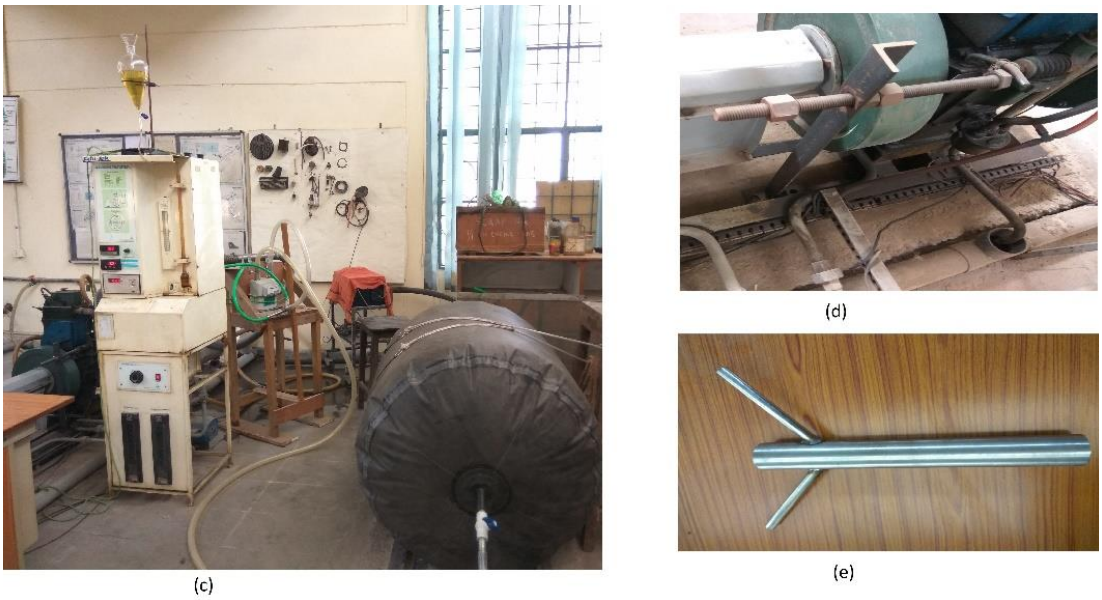



Fig. 2 Visual depiction of (a) refitted engine setup, (b) regulating lever and (c) fuel-air mixing chamber

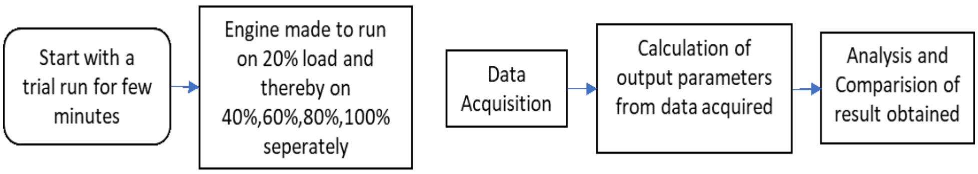



Fig. 3 Process Chart for single fuel mode

placed at different points and continuous data are recorded with the help of PT100 sensors. These sensors are connected to a NI unit that registers signals and transfers those to the computer via software. To achieve dual fuel operation, a gas-air mixing device is added to the setup. The gas-air mixing device was designed using the data from engine specifications. The pictorial representation and the schematic diagram of the experimental setup and gas mixer have been presented in Fig. 1 and Fig. 2.

Three modes of operation were carried out in this experiment and a comparison was made between them after undergoing energy and exergy analysis. A single fuel mode and two biogas run modes were considered. In one of the Biogas run mode, diesel was substituted with a B20 blend of Linseed Biodiesel. The experiment was started with the diesel mode and the readings were recorded for each load after engine stabilization. For dual fuel mode operation, the engine was made to run and match the rpm recorded in the single pilot fuel mode. With the help of the governor, the engine auto adjusts and matches the diesel rpm to a certain extent. To realize an actual replacement of pilot fuel with biogas, a regulating lever was utilized and hence the rpm is approximately matched in the dual fuel mode to the single fuel mode. After the engine data recordings were made, calculations were done for energy and exergy analysis with the help of the 1st and 2nd laws of thermodynamics.

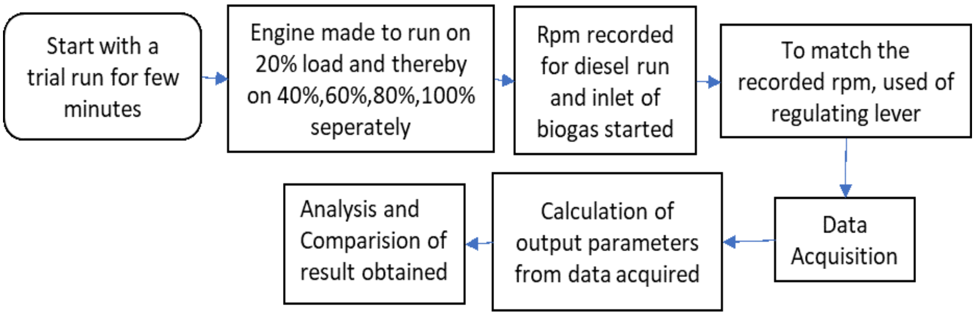
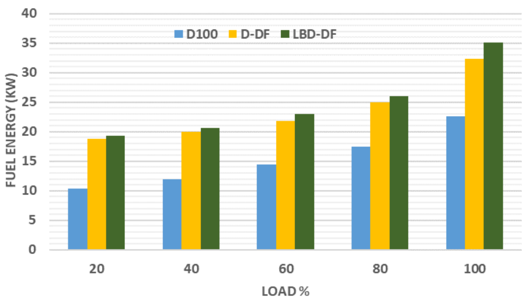
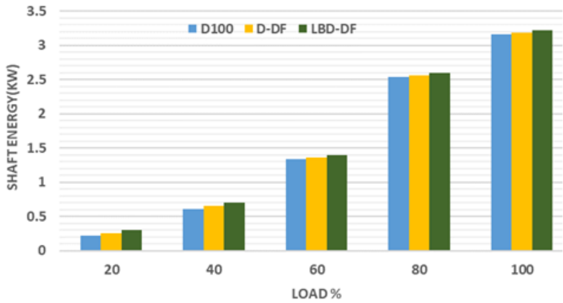


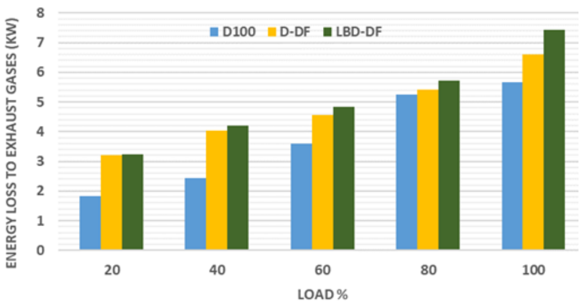

Fig. 4 Process Chart for Biogas run mode



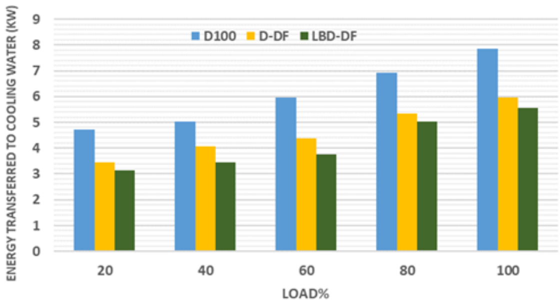

(a) Fuel Energy



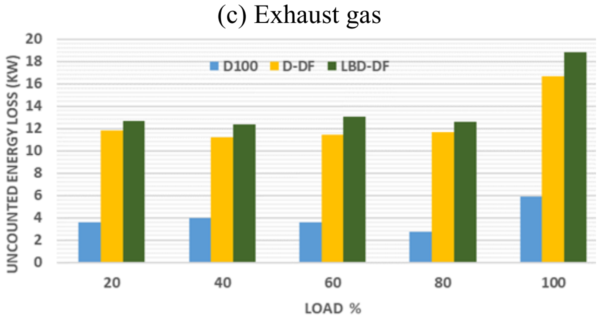

(b) Shaft work



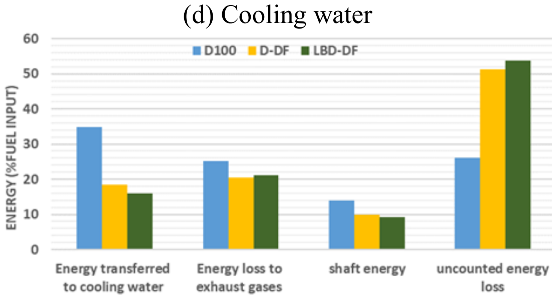

(c) Exhaust gas




(d) Cooling water




(e) Uncounted energy loss




(f) Distribution with respect to fuel input at 100% load

Fig. 5 Energy Relocation

## 4. Results and discussions

### 4.1 Energy analysis

For all the mode of operation, a study on the data’s obtained from the engine using the first law of thermodynamics is presented. The energy supplied in a system is conserved in its various processes and elements of the system, according to the First Law of Thermodynamics. It provides important information about the proper distribution of energy supplied by fuel in various parts of the engine [9]. The fuel energy supplied to a CI engine is relocated in several processes: shaft energy, cooling water, exhaust gases, and uncounted loss.

Both evaluated dual fuel modes needed more input fuel energy at low to medium loads than diesel mode. The reason is for engine operation in lower loads, lower temperature results in weak combustion qualities. With the increase in load, the difference gap in fuel energy required narrowed because of better combustion achieved in dual fuel modes. For the maximum load, the fuel energy required for the biogas run operations rose due to the decline in oxidation possibility required for complete combustion, again increasing the gap between diesel and dual fuel mode operation. Because fuel energy is a factor of the lower heating value of the fuel, it was realized that the biodiesel dual fuel mode had the maximum fuel energy. The fuel energy required at the input for the highest load was observed to increase by 10.14% and 12.9% for Diesel-biogas mode and Biodiesel-biogas mode respectively in comparison to the diesel mode

The difference in energy relocated to Shaft work observed at various loads for all modes of operation is negligible. However, the shaft work when considered as a percentage of fuel input differs due to differences in fuel heating value for all fuels. Shaft work for all modes of operation increases as load increases. In general, increasing the load improves by boosting combustion temperatures and maximum cylinder pressure while reducing combustion time. Though the input shaft energy has negligible difference among all, at the highest load an increase of 0.94% and 1.4% for diesel-biogas mode and biodiesel-biogas mode respectively were observed in contrast to the diesel single fuel mode.

Due to the high cylinder wall loss, the energy transferred to cooling water in dual biogas mode operations is significantly lesser than in the single fuel mode. This is because, despite the substantially larger fuel energy for dual fuel modes in contrast to single fuel mode, the amount of rise in engine cooling water temperature in the biogas mode of operation is lower. For the highest load, a reduction of 24.07% and 29.17% was observed for diesel-biogas mode and biodiesel-biogas mode in comparison to the diesel mode.

At all load levels, dual fuel operations with biogas fuels produced considerably more exhaust gas temperatures than diesel mode owing to the gaseous fuels' delayed and insufficient combustion period in biogas run dual fuel mode. For both dual fuel modes, this results in higher energy losses to exhaust gases. For the highest load, an increase of 35.5% and 65% were observed for diesel-biogas mode and biodiesel-biogas mode when compared with the single fuel mode.

Uncounted losses include the energy input from the fuel, energy transfers to the cooling water, exhaust gas, and shaft work. Because the fuel energy input of biogas run mode is more than the single fuel mode, the uncounted losses are also higher for dual fuel. With increasing load, the amount of uncounted losses increases. The uncounted losses of energy for the highest load were observed to increase 180% and 220% for Diesel-biogas mode and Biodiesel-biogas mode respectively in comparison to the single fuel mode.

### *4.2 Exergy analysis*

Even though we can find the energy transformations using the first law of analysis, there are further losses at each stage, so only a portion of the energy is available after the losses. A performance analysis that leverages the 2nd law of thermodynamics to circumvent the restrictions of a 1st law or energy analysis is known as an exergy analysis. 2nd law analysis reveals numerous types of energy with varying degrees of capacity to do the mechanical task that is useful. The capacity to conduct meaningful mechanical tasks is denoted as availability. The fuel exergy is relocated into different exergy types inside of the IC engine. The fuel exergy of an engine is relocated to several processes: shaft, cooling water, exhaust gases, and exergy destroyed.

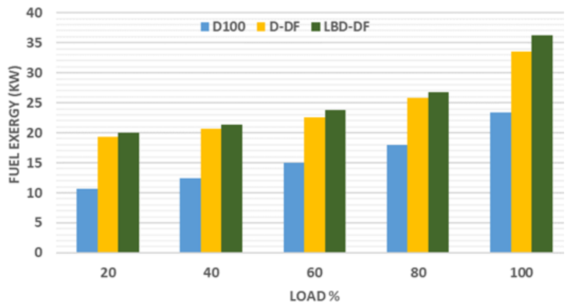
The stoichiometric ratio increases with the increase in load. With the increase in load a relatively rich fuel intake results in raising the combustion temperature leading to rise in fuel exergy. However, combustion efficiency decreases for the highest load due to insufficient oxygen. This further reduces fuel exergy for the highest load. Due to the poor combustion and low energetic biogas fuel, dual fuel modes required higher chemical fuel exergy than diesel mode to maintain an equal power output. For an increase in load, the supply of fuel exergy in dual fuel modes converged to that of diesel mode. This is due to the better combustion of biogas at higher temperature loads. We observe a lower fuel exergy for the biodiesel dual fuel mode due to the lower calorific value of linseed biodiesel compared to diesel. The fuel exergy achieved at the input for the highest load was observed to increase by 43.33% and 55.29% for Diesel-biogas and Biodiesel-biogas mode respectively in comparison to the single fuel mode

A hike in load causes an increase in cylinder temperature, which leads to more heat loss to the cylinder walls. As a result, an increase in exergy transfer to cooling water is observed. More heat loss to walls of cylinder is observed for biogas run mode, and cooling availability for biogas run mode is lower than in the single fuel mode. For the biogas mode of operation, the amount of rise in engine cooling water temperature is lower in contrast to the substantially larger fuel energy input of diesel mode. Though the input shaft exergy has negligible difference among all, at the highest load an increase of 0.94% and 1.4% for diesel-biogas mode and biodiesel-biogas mode respectively were observed in comparison to the single fuel mode.

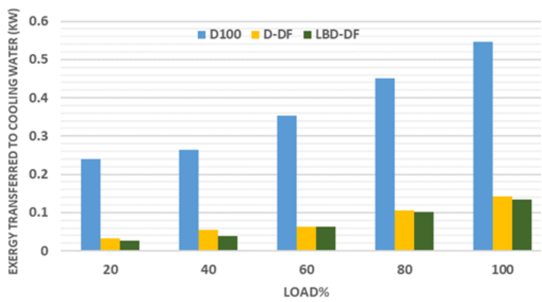
A hike in load causes an increase in cylinder pressure, which leads to more heat loss to exhaust gases. As a result, an increase in exergy transfer to exhaust gases is observed. For the entire load range, biogas run modes exhibit higher exhaust gas temperatures than diesel mode. This results in increased exhaust gas exergy for biogas run mode. The linseed biodiesel dual fuel mode has the highest exhaust gas temperature of all the modes studied, so the exergy transferred to exhaust gases is also higher. For the highest load, a reduction in exergy relocated to colling water of 73.7% and 75.1% was observed for diesel-biogas mode and biodiesel-biogas mode in comparison to the single fuel mode.

With an increase in load, the availability destruction increases because of larger cylinder temperatures, shorter combustion times, and lower entropy generation during combustion. Poor combustion of biogas fuels caused lesser cooling water availability and exhaust gas availability at low loads (up to 40%), resulting in higher destroyed availability. For the highest load, an increase of 35.5% and 65% were observed for diesel dual fuel mode and biodiesel dual fuel mode in comparison to the diesel mode for the exergy relocated to exhaust gases.

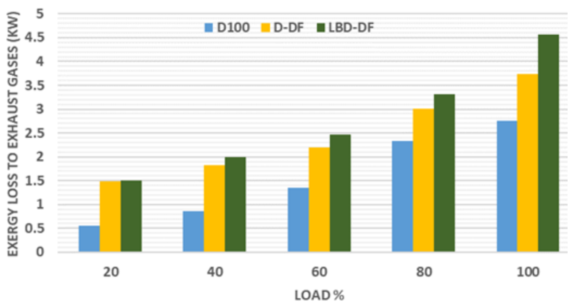
The second-law efficiency versus load for single fuel mode and biogas run mode is depicted in Fig. 6(f). The efficiency of the second law increased till 80% load and then decreased for 100% load due to the reduction in combustion speed. The combination of work, exhaust gas, and cooling



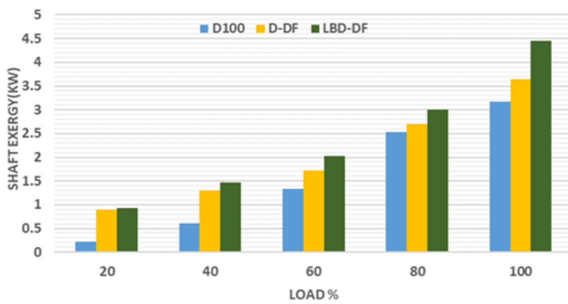
(a) Fuel Energy



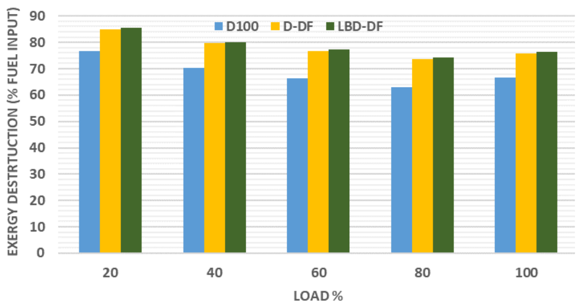
(b) Cooling water



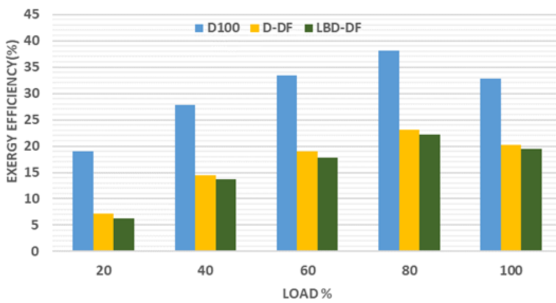
(c) Exhaust gas



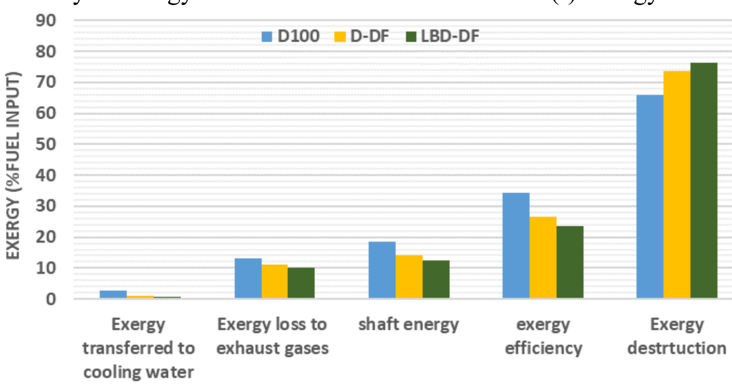
(d) Shaft exergy



(e) Destroyed Exergy



(f) Exergy efficiency



(f) Exergy distribution with respect to fuel input for 100% load

Fig. 6 Exergy Relocation

water availability all observed a hike with an increment in load. The availability of gross work output increased the corresponding exergy efficiency. Furthermore, a load increment improved the combustion mechanism from the standpoint of the second law. Increased combustion temperatures and decreased combustion span with a hike in load both reduce combustion irreversibility. The higher the exergy efficiency, the lower the irreversibility, and vice versa. For the highest load, the exergy efficiency of diesel, diesel dual fuel mode, and linseed biodiesel dual fuel mode is analyzed to be 34.2%, 26.5 %, and 23.59% respectively. For the highest load, the destroyed availability is analyzed to be 65.8%, 73.5%, and 76.41% for single fuel mode, diesel-biogas mode, and linseed biodiesel-biogas mode respectively.

## 5. Conclusions

The conclusions we obtained from this experiment are:

- With respect to the fuel input energy, the energy relocated to cooling water at the highest load translates to 34.78%, 18.4%, and 15.86 % for single fuel mode, diesel-biogas mode, and linseed biodiesel-biogas mode respectively. With respect to the fuel input exergy, the exergy relocated to cooling water at the highest load translates to 2.6%, 1.2%, and 0.8 % for single fuel mode, diesel-biogas mode, and linseed biodiesel dual fuel mode respectively.
- With respect to the fuel input energy, the energy relocated to exhaust gas at the highest load translates to 25.12%, 20.3%, and 21.18 % for single fuel mode, diesel-biogas mode, and linseed biodiesel-biogas mode respectively. With respect to the fuel input exergy, the exergy relocated to exhaust gases at the highest load translates to 13%, 11% and10 % for single fuel mode, diesel-biogas mode, and linseed biodiesel-biogas mode respectively.
- With respect to the fuel input energy, the energy relocated to shaft work at the highest load translates to 14.03%, 9.85%, and 9.18 % single fuel mode, diesel-biogas mode, and linseed biodiesel-biogas respectively. With respect to the fuel input exergy, the exergy relocated to shaft work at the highest load translates to 18.5%, 14%, and 12.5 % for single fuel mode, diesel-biogas mode, and linseed biodiesel-biogas mode respectively.
- For the highest load, the destroyed availability is analyzed to be 65.8%, 73.5%, and 76.41% for single fuel mode, diesel-biogas mode, and linseed biodiesel-biogas mode respectively.
- The exergy efficiency of single fuel mode, diesel-biogas mode, and linseed biodiesel-biogas is analyzed to be 34.2%, 26.5 %, and 23.59% respectively.

Since the exergy efficiency between the diesel run on dual fuel and biodiesel run on dual fuel exhibit a difference of only 3%, it can be concluded that the linseed biodiesel blend can be considered as a substitute for diesel in CI engine.

## References

Abbasi, A. and Emamverdi, O. (2014), "Influence of nozzle hole diameter on the first and second law balance in a DI Diesel engine", *J. Power Technol.,* **94**(1), 20-33.

Açikkalp, E., Yamik, H. and Içingür, Y. (2014), "Performance of a compression ignition engine operated with sunflower ethyl ester under different engine loads", *J. Energ. Southern Africa*, **25**, 81-90.

Aghbashlo, M., Tabatabaei, M., Mohammadi, P., Pourvosoughi, N., Nikbakht, A.M. and Goli, S.A.H. (2015), "Improving exergetic and sustainability parameters of a DI diesel engine using polymer waste dissolved in biodiesel as a novel diesel additive", *Energ. Convers. Manage.*, **105**, 328-337. https://doi.org/10.1016/j.enconman.2015.07.075.

Azoumah, Y., Blin, J. and Daho, T. (2009), "Exergy efficiency applied for the performance optimization of a direct injection compression ignition (CI) engine using biofuels", *Renew. Energ.*, **34**(6), 1494-1500. https://doi.org/10.1016/j.renene.2008.10.026.

Caliskan, H., Tat, M. E. and Hepbasli, A. (2009), "Performance assessment of an internal combustion engine at varying dead (reference) state temperatures", *Appl. Therm. Eng.*, **29**(16), 3431-3436. https://doi.org/10.1016/j.applthermaleng.2009.05.021.

Fathi, M., Ganji, D.D. and Jahanian, O. (2020), "Intake charge temperature effect on performance characteristics of direct injection low-temperature combustion engines", *J. Therm. Anal. Calorimetry*, **139**(4), 2447-2454. https://doi.org/10.1007/s10973-019-08515-y.

Jafarmadar, S. and Nemati, P. (2016), "Exergy analysis of diesel/biodiesel combustion in a homogenous charge compression ignition (HCCI) engine using three-dimensional model", *Renew. Energ.*, **99**, 514-523. https://doi.org/10.1016/j.renene.2016.07.034.

López, I., Quintana, C.E., Ruiz, J.J., Cruz-Peragón, F. and Dorado, M.P. (2014), "Effect of the use of olive–pomace oil biodiesel/diesel fuel blends in a compression ignition engine: Preliminary exergy analysis", *Energ. Convers. Manage.*, **85**, 227-233. https://doi.org/10.1016/j.enconman.2014.05.084.

Meisami, F. and Ajam, H. (2015), "Energy, exergy and economic analysis of a diesel engine fueled with castor oil biodiesel", *Int. J. Engine Res.*, **16**(5), 691-702. https://doi.org/10.1177/1468087415576609.

Murugesan, A., Umarani, C., Subramanian, R. and Nedunchezhian, N. (2009), "Bio-diesel as an alternative fuel for diesel engines—A review", *Renew. Sust. Energ. Rev.*, **13**(3), 653-662. https://doi.org/10.1016/j.rser.2007.10.007.

Özkan, M. (2015), "A comparative study on energy and exergy analyses of a CI engine performed with different multiple injection strategies at part load: Effect of injection pressure", *Entropy*, **17**(1), 244-263. https://doi.org/10.3390/e17010244.

Ptasinski, K. (2016), Author Index. In *Efficiency of Biomass Energy*, John Wiley & Sons, Inc. https://doi.org/10.1002/9781119118169.indauth.

Rahman, M., Mohamme, M.K. and Bakar, R.A. (2009), "Air fuel ratio on engine performance and instantaneous behavior of crank angle for four cylinder direct injection hydrogen fueled engine", *J. Appl. Sci.*, **9**(16), 2877-2886. https://doi.org/10.3923/jas.2009.2877.2886.

Rakopoulos, C.D. and Kyritsis, D.C. (2001), "Comparative second-law analysis of internal combustion engine operation for methane, methanol, and dodecane fuels", *Energy*, ***26***(7), 705-722. https://doi.org/10.1016/S0360-5442(01)00027-5.

Ramos da Costa, Y.J., Barbosa de Lima, A.G., Bezerra Filho, C.R. and de Araujo Lima, L. (2012), "Energetic and exergetic analyses of a dual-fuel diesel engine", *Renew. Sust. Energ. Rev.*, **16**(7), 4651-4660. https://doi.org/10.1016/j.rser.2012.04.013.

Rosen, M.A. (2006), "Benefits of exergy and needs for increased education and public understanding and applications in industry and policy - Part II: Needs", *Int. J. Exergy*, **3**(2), 219. https://doi.org/10.1504/IJEX.2006.009046.

Sayin, C., Hosoz, M., Canakci, M. and Kilicaslan, I. (2007), "Energy and exergy analyses of a gasoline engine", *Int. J. Energ. Res.*, **31**(3), 259-273. https://doi.org/10.1002/er.1246.

Sharma, A., Singh, Y., Ahmad Ansari, N., Pal, A. and Lalhriatpuia, S. (2020), "Experimental investigation of the behaviour of a DI diesel engine fuelled with biodiesel/diesel blends having effect of raw biogas at different operating responses", *Fuel*, **279**, 118460. https://doi.org/10.1016/j.fuel.2020.118460.

Sorathia, H. and Yadav, H. (2012), *Energy analyses to a ci-engine using diesel and bio-gas dual fuel—a review study*, **1**, IJAERS.

Taqizadeh, A., Jahanian, O. and Kani, S.I.P. (2020), "Effects of equivalence and fuel ratios on combustion characteristics of an RCCI engine fueled with methane/n-heptane blend", *J. Therm. Anal. Calorimetry*, **139**(4), 2541-2551. https://doi.org/10.1007/s10973-019-08669-9.

Tat, M.E. (2011), "Cetane number effect on the energetic and exergetic efficiency of a diesel engine fuelled with biodiesel", *Fuel Process. Technol.*, **92**(7), 1311-1321. https://doi.org/10.1016/j.fuproc.2011.02.006.