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Use of solar energy in biodiesel production and performance-emission analysis of biodiesel produced

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ABSTRACT: In recent years, fossil fuels are rapidly diminishing due to increasing demand. Biodiesel has been renowned as an alternative fuels since it is produced mainly from vegetable oils and animal fats. Transesterification is the most commonly used biodiesel production process in which triglyceride is heated with alcohol and catalyst. If this heating process in transesterification can be done by the renewable source, the overall cost of biodiesel production could be reduced. In this work, solar energy was employed for chemical heating in transesterification project. Various process parameters for the optimization of biodiesel production were investigated. Also, performance test of a diesel engine with neat diesel fuel and biodiesel mixtures were carried out. The oil used for biodiesel production was Cottonseed oil (CSO) which is non-edible oil, thus fuel versus food conflict will not arise if CSO is used for biodiesel production. The solar assisted transesterification results depicted that yield of biodiesel varied with the variation of catalyst (KOH),methanol, reaction time and temperature. However, a maximum of 93.6% biodiesel was produced with16.67% methanol in presence of 1.0% potassium hydroxide at reaction temperature 70˚C and reaction time 40 min. The emission analysis of different blends of biodiesel with diesel depicted that the overall emissions of Biodiesel is lower than engine emission of diesel. The only hindrance is that, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel blends.

I. INTRODUCTION

It is well known fact that fossil fuel constitute a finite resource, so biofuel can be an alternative source of energy in place of petroleum fossil fuels. Biofuels are generally organic combustibles derived from biomass. These are mainly used for combustion to produce heat for industrial processes, electricity generation and heat engine carburation in IC engines. Edible and Non-edible different kinds of crops used as feedstock material for biodiesel. Generally, biodiesel is produced by transesterification of feedstock oil. In the present scenario, although petroleum-based fuels can't be entirely replaced by biodiesel, there are various advantages of biodiesel over diesel fuel. It is biodegradable and more than 90% biodiesel can be biodegraded within 21 days. Cetane number and combustions efficiency are higher for biodiesel than in case of diesel fuel. The Sulfur and aromatic content is lower in case of biodiesel i.e. use of biodiesel for combustion process in engines does not produce toxic emission gases. Additionally, it reduces most exhaust emissions such as monoxide, unburned hydrocarbons, and particulate matter except oxides of nitrogen (NO_x) [1].

II. LITERATURE SURVEY

Biodiesel production process can be made cost effective if the heating required in transesterification is done by the use of solar energy. Agee et al. [2] discussed the production of biodiesel using solar energy for processing heat in transesterification. In this work, a parabolic solar reflector made of satellite dishes was developed to concentrate solar irradiation on its focal point. Feedstock oil with alcohol and catalyst was placed on the focal point of the reflector and then transesterification process takes place in approximately in one hour. In this work soybean oil was used as feedstock oil. For successful processing of transesterification, solar irradiation should be greater than 400-450 W/m^2. The result indicates that solar assisted biodiesel production is successful at milli-molar and small molar scale. So further improvisation is needed to enhance the quality of biodiesel production. Design modification such as making large size of solar reflector should be developed.

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Hou et al. [3] proposed a new concept of utilizing solar energy application to supply steam and electricity for biodiesel production. As in the biodiesel production process, the combustion of fossil fuels takes place to supply steam and electricity needed for the refinement of crude fatty acid methyl ester (FAME). In this process, some pollutant gases such as CO_2, NO_x and SO_x are also released into the environment. To reduce these disapproving condition, solar energy appliances can be utilized.

III. DESIGN OF EXPERIMENTS USING TAGUCHI'S METHOD

In this method, a 3-level 4-factor design of experiment was used to optimize biodiesel production process. The four factors upon which conversion yield of biodiesel depends are- Molar Ratio, Reaction Time, Reaction Temperature and Catalyst concentration. KOH was used as catalyst. Different levels of factors and orthogonal array based upon these values are tabulated as follow-

Table 1: Factors and levels for design of experiments

	Factors			
Level	Molar Ratio	Time (min)	Temperature (˚C)	Catalyst Conc. (wt%)
1	4.5:1	20	50	0.50
2	6:1	30	60	0.75
3	7.5:1	40	70	1.00

Based on these levels and factors L9 orthogonal array was adapted in Taguchi's analysis and subsequently 9 experiments were performed.

Table 2 – L9 Orthogonal Array

	Levels of design for different Factors				
S. No.	Molar Ratio	Time	Temperature	Catalyst Concentration	**Yield (%)**
1.	1	1	1	1	88.28
2.	1	2	2	2	90.10
3.	1	3	3	3	92.46
4.	2	1	2	3	91.70
5.	2	2	3	1	93.32
6.	2	3	1	2	91.00
7.	3	1	3	2	91.84
8.	3	2	1	3	90.50
9.	3	3	2	1	92.24

Based on the experiments performed according to the above L9 orthogonal array, Taguchi's analysis showed the mean effective plots for mean value of yield with respect to the four parameters (Molar Ratio, Reaction Time, Reaction Temperature and Catalyst Concentration) as shown in figure 1. The model used in Taguchi's analysis was

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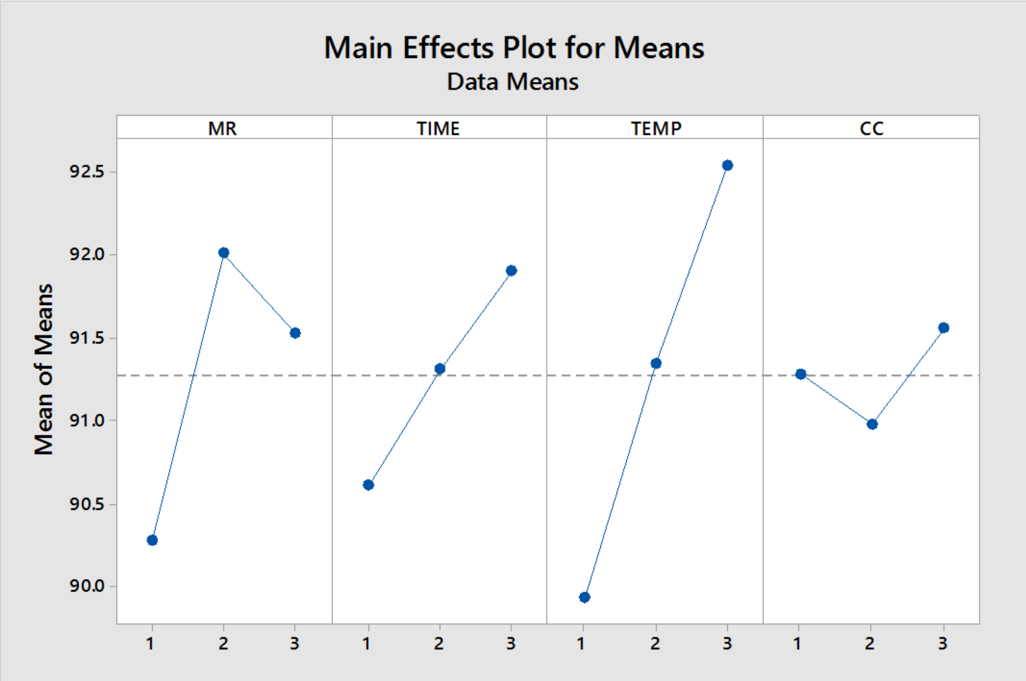

Figure 1. Main effects plots of Yield with respect to various process parameter

The main effect plots for Mean value of conversion yield and signal to noise ratio depict that the best condition for the maximum yield of biodiesel is-

- **Molar Ratio 6:1, Reaction Time 40 minutes, Reaction Temperature 70˚C and KOH concentration 1.0 % by weight.**

The experiment was performed on the above optimized condition and the conversion yield of biodiesel was found 93.60% which is better than the 9 experiment performed previously according to L9 orthogonal array.

IV. EXPERIMENTAL PROCEDURE

In this experiment, there is a requirement to maintain the flux temperature around 70˚C for 20-40 min depending upon the solar irradiation. As long as there is enough sun present to produce at least 400W/m^2 of solar irradiation, effective heating can be achieved in a reasonable amount of time. The cotton seed oil quantity used was 500 gram and other process parameters such as oil to methanol molar ratio, reaction time, reaction temperature and catalyst (KOH) concentration according to the iterations shown by L9 orthogonal array. Steps in this process of solar-assisted transesterification are with the help of diagram in following paragraphs-

i. Take 500 gram of cotton seed oil and heat up the oil using solar energy to remove the moisture present in it.
ii. Then cool the heated oil up to 60˚C in ambient air.
iii. Prepare a mixture of methanol and catalyst (KOH) in separate beaker and pour this solution into cotton seed oil after mixing.
iv. Now flux temperature is maintained around 50˚C-70˚C for 20-40 min according to iterations shown in orthogonal array. In this way, the transesterification reaction is accomplished properly which convert triglyceride into mono-glyceride.
v. After completion of transesterification, two layers appears in the beaker. The lower layer is of glycerol which is higher in density and appears as dark brown colour. The upper layer is of cottonseed oil methyl ester (CSOME) which is our required product.
vi. CSOME is separated from glycerol using a burette and the crude biodiesel is purified using the water washing process. In this process, warm water (30% of oil quantity at 60˚C) is poured into the crude CSOME and the contaminants of remaining alkali catalyst are neutralized due to water washing process.
vii. The final product is gained by heating the CSOME after water washing to remove remaining water content. Thus, quality of biodiesel production is maintained.

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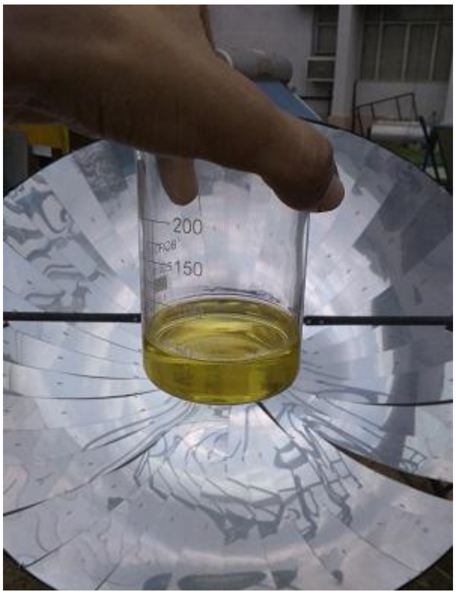
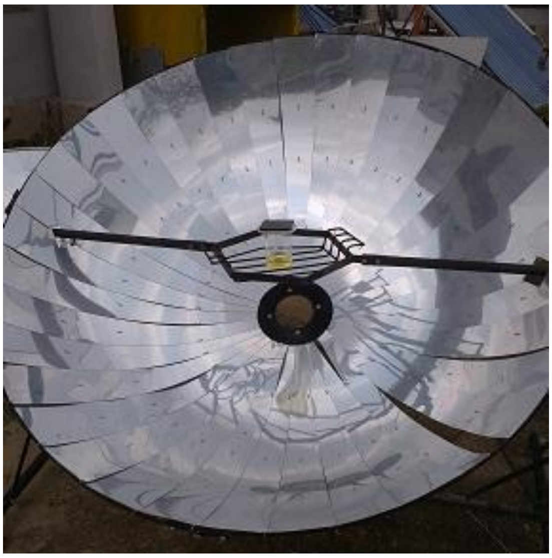
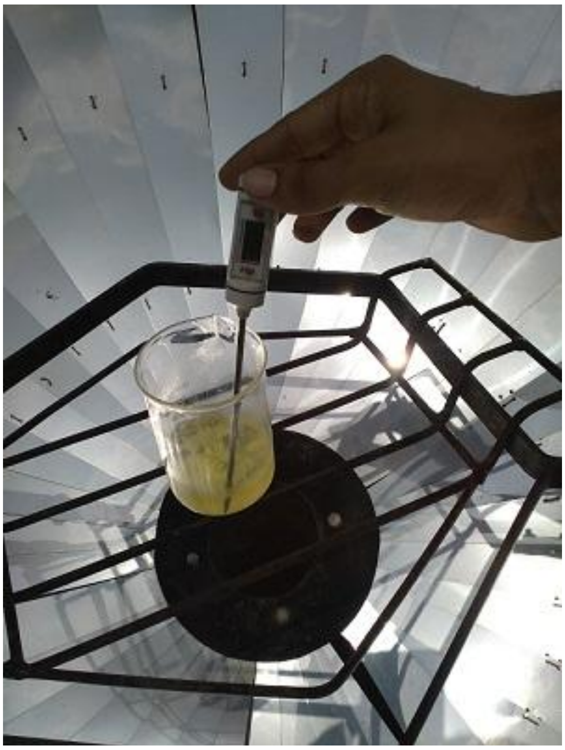


2(a) Cotton seed oil used


2(b) heating of oil before transesterification


2(c) Measuring temperature of mixture


2(d) two beakers system to maintain temp.

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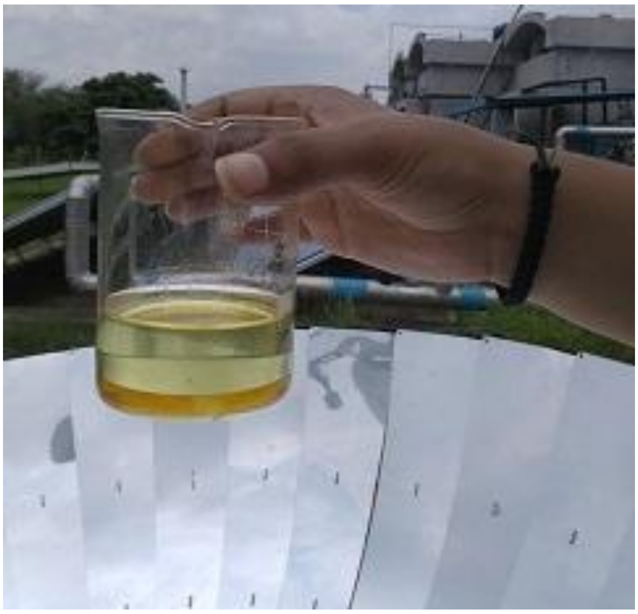

2(e) Prepared crude biodiesel after transesterification

2(f) preparation of different sample at same time

Figure 2. Various process of Solar assisted Biodiesel Production

V. PHYSIO-CHEMICAL PROPERTIES OF BIODIESEL (CSOME)

Table 3: Properties of Biodiesel (CSOME)

Name of Properties	Diesel	CSOME
High Calorific Value (MJ/kg)	42.232	39.5
Density (kg/m^3)	0.831	0.9148
Kinematic Viscosity@ 40°C(mm^2/s)	3.21	18.2
Cloud Point, °C	-12	1.7
Pour Point, °C	4	12
Flash Point, °C	66	110
Cetane Number	43	52

The table 3 depicts that the properties of biodiesel (CSOME) produced from cottonseed oil is comparable to the properties of diesel. Hence it can be used in vehicle with and without making its blends with diesel.

VI. RESULT AND DISCUSSIONS

The brake specific fuel consumption (BSFC), Brake thermal efficiency(BTE), emission against engine load are presented in Figures 3 & 4.The Brake-specific fuel consumption (BSFC) is the ratio between mass flow of the tested fuel and effective power. Fig 3 represents the BSFC variation with power output at engine speed of 1500 rpm for diesel, biodiesel, and their blends. In general, the BSFC is found to increase with raising the biodiesel quantity with the blends under all ranges of engine load. The BSFC of a diesel engine depends on the relationship among volumetric fuel injection system, fuel specific gravity, viscosity, and heating value. When increasing biodiesel proportion in blends, calorific value decreases and leads to increase the flow rate of the blends for maintaining the same operating conditions.

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As expected, load increases, the BSFC decreases for all fuels. At brake power (5.2 kW), C10 and C20 are found to be the blends that give lower BSFC.

The brake thermal efficiency of Fig. 4 shows an increase with engine load as the amount of the Cotton seed oil in the blends increases. It can be seen from Fig. 4 that the 90% diesel to 10% Cotton seed oil fuel blend incidentally gives higher efficiencies at all loads. The diesel fuel produced the lowest thermal efficiency at all loads. The higher thermal efficiency of the vegetable oil fuels may be due to their low heat input requirement for a given engine load. The BTE of C10 and C20 blends is increased around 6% at brake power of 5.2 kW when compared to diesel.

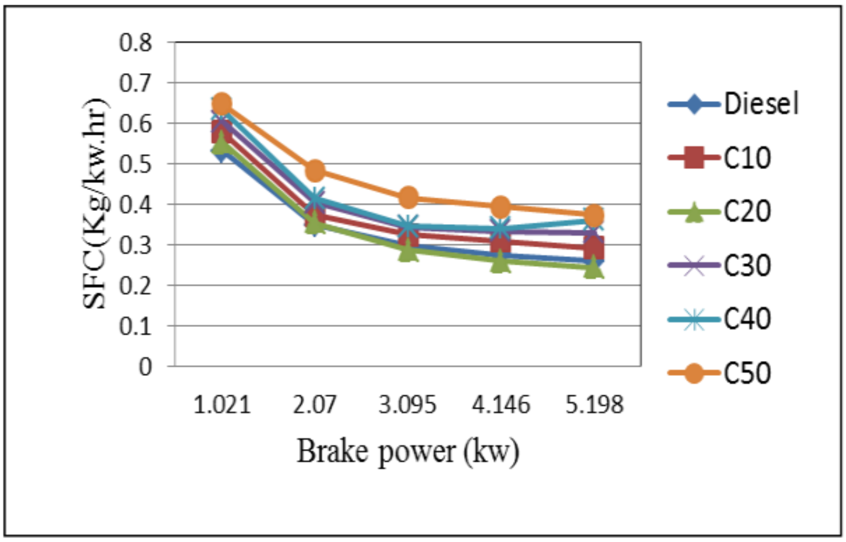

Figure 3- Effect of brake power on specific fuel consumption

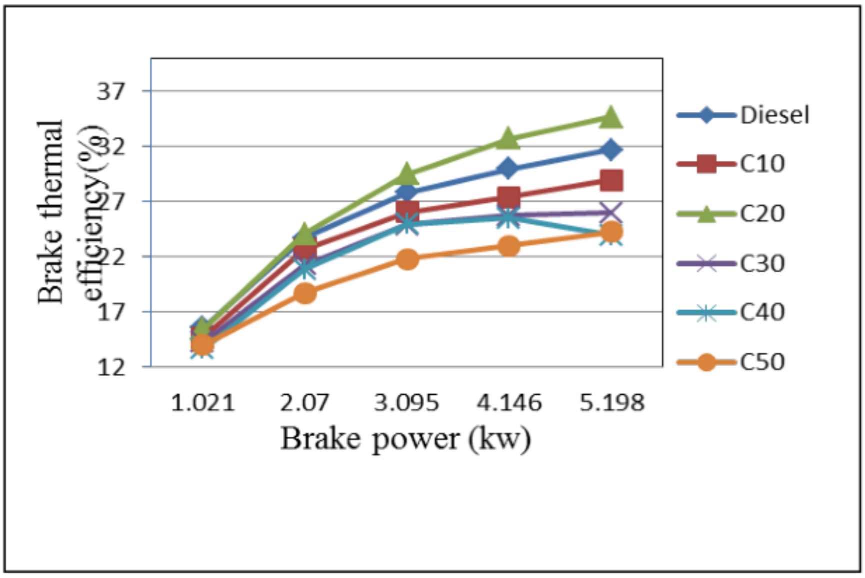

Figure 4- Effect of brake power on brake thermal efficiency

Effect of load on HC emission-

It is an important parameter for determining the emission behaviour of the engine. The variation of unburned hydrocarbon (HC) with load for the tested fuels is given in Fig. 5. It is shown that increasing biodiesel in the blends reduces significantly HC emissions comparatively to ordinary diesel. This is due to the increase in oxygen content in the blend which improves the combustion quality in the combustion chamber. It can be noticed that at high power levels for C20 (e.g.-5.2 kW), the reduction in HC emissions can reach 50% in comparison with neat diesel fuel.

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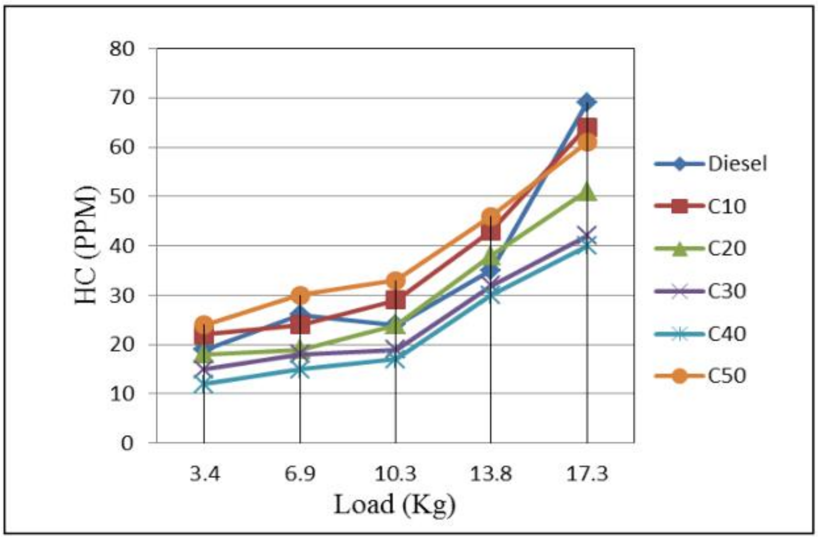

Figure 5- Effect of load on Hydrocarbon emission

Effect of load on CO emission-

The plot of Fig. 6 shows the variation of carbon monoxide (CO) emission of Cotton seed oil bio diesel with ordinary diesel at various load conditions. It is shown that increasing biodiesel in the blends at low and middle engine loads has only a slight effect on the CO emissions due to the dominant premixed lean combustion with excess air.

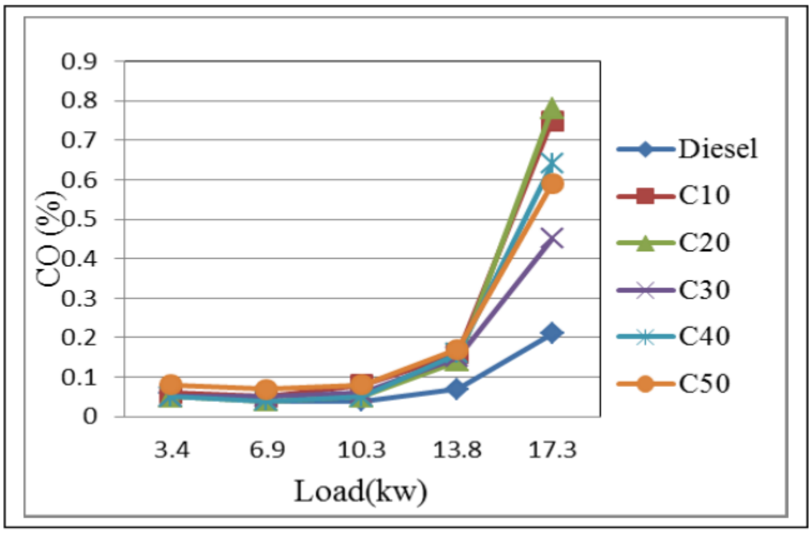

Figure 6- Effect of load on CO emission

The CO emissions of C20 at loads 3.4, 6.9, 10.3 kW are evidently lower than those of diesel fuel. This is becausebiodiesel, which contains more number of oxygen atoms, leads to much complete combustion.

Effect of load on NO_x emission-

Fig. 7 points out the variation of nitrogen oxides (NOx) emission with power output for the different fuels tested. There are mainly three factors, oxygen concentration, combustion temperature, and time, affecting the NOx emission. As the load increases, the concentration of NOx is also increasing. The graph clearly shows the diesel NOx is always higher than the biodiesel. Comparing the overall results the C30 blend exhibits lower NOx emission but its BTE is low when compared to C20 blend. However, the NOx emission was decreased for C10, C20, C30 and C40 when compared to neat diesel. At partial loads NOx emissions of neat biodiesel and its blends are higher than those of diesel fuel. Higher values of combustion temperature and presence of oxygen with biodiesel result in an increase in NOx generation.

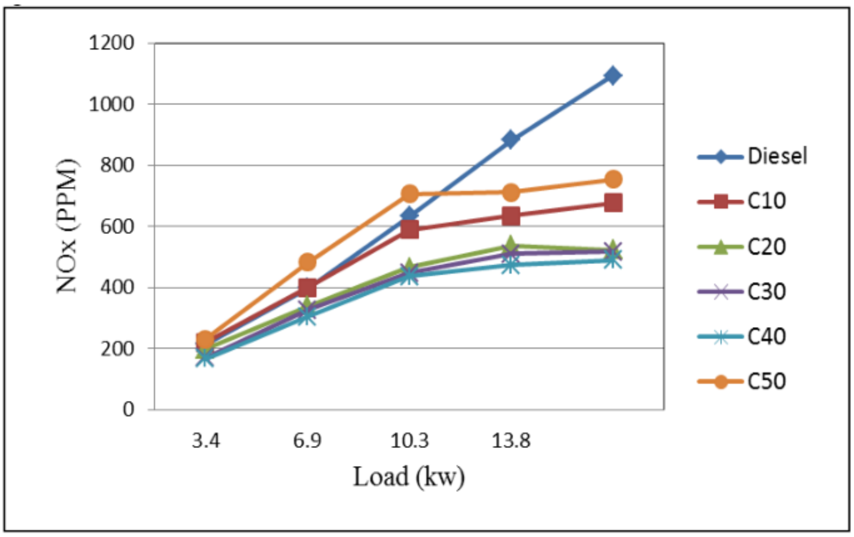

Figure 7- Effect of load on NO_x emission

CONCLUSION

In the future, researches should be focused on optimizing the transesterification process using the solar energy and efforts should be made to use this method commercially. Selection of site for solar assisted production of biodiesel is also a field in which there is a need to do further research. If such kind of setups are installed in a location where the availability of biodiesel feedstock is easily available, the transportation cost of supplying feedstock to biodiesel production plant can be reduced. The sunshine should be better at installation location as we need more than 400 W/m^2intensity of solar radiation for transesterification. In India, we can think to develop such kind of setup in Rajasthan, Gujrat, Haryana and all those place where the availability of sun shine remains sufficient throughout the year.

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