Parametric Analysis of a Safflower Bio Diesel on a C I Engine with Engine & Fuel Modifications

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Abstract: **The area of Alternate fuels has many challenges related to sources as well as running of the Machine. The availability, extraction of crude oils, Food Protocols, Energy content etc... are source challenges. By the properties of fuel atomization, proper combustion, emissions are the machine challenges.**

Based on the Source challenges Safflower is considered as a source and to achieve the machine challenges the parameters like blends of Fuel, Compression Ratio & Injection Timing are considered.

The research is focused to study the engine products i.e. Performance parameters and Engine Bed Vibrations of a safflower bio diesel blends at different compression ratios and injection timings. To the best combination w.r.t to the blend, Compression Ratio and Injection Timing the Nano particles i.e. Cerium Oxide (CeO2), Aluminium Doped with Titanium Oxide (AlTiO2) are added and Results are investigated.

Keywords* — *Alternate fuels, Bio Diesel, Engine Modifications, Fuel additives, Engine Vibrations.

I. Introduction

Internal combustion engine commonly called as IC Engine used for production of Mechanical energy(shaft power) from Chemical energy (fuel) with the help of different systems like Ignition, Lubrication system etc... Rudolf Diesel Invented the IC Engine running with Peanut oil as a fuel to help the Farmers. The Area of energy in the world facing many problems due to lake of fossil based fuels. Fossil based Diesel fuel and Petrol are commonly used for running of the IC Engine. Day by day fossil fuel sources are decreasing but usage of fuel is increasing due to people luxury.

The safflower is a plant, flowers and seed oil are used in ayurvedic medicine and cooking etc… the flowers are used as a cheaper substitute for saffron. Due to huge oil sources, energy content the safflower is considered as a source for bio diesel.

II. Materials & Methods

Safflower oil is collected from local market, Fossil based diesel fuel is purchased in fuel bunk. Required chemicals are purchased in chemicals store.

A. Bio Diesel Production

Safflower bio diesel is produced by Transesterification process in the presence of Methanol an NaoH as a Catalyst. The Neat and dried safflower oil is reacted with 13% of Methanol and 1% NaoH as a Catalyst. The Magnetic stirrer is set to 700 rpm and temperature is set to 700C. now this solution is transferred to a separating funnel to separate the glycerine & Methyl ester and post treatment is done to get the salt free and moisture free Bio diesel.

B. Overview of Experimentation

The Experimentation is done on a Computerized Variable Compression Ratio Direct Injection Water cooled Engine. The analysis is done with the blends of bio Diesel with the diesel fuel at a Proportion rate of 10%, 20%, 30%, 100% at a Compression Ratio of CR16, CR17, CR18with an injection timing of Crank angle 21^o before top dead centre (INJT CA 21^0 BTDC). For the best combination the injection pressure is varied with INJT CA 22^0 BTDC, INJT CA 23^0 BTDC.

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Fuel Blend	Compression Ratio	Injection Timing	Nano Additives (Cerium Oxide)	Nano Additives (Aluminium Doped with titanium)
B0	CR16			
	CR17			
	CR18			
B10	CR16			
	CR17			
	CR18	INJT CA 21^0 BTDC		
		INJT CA 22^0 BTDC	CeO2 25 mg	AlTio2 25mg
			CeO2 50 mg	AlTio2 50mg
			CeO2 75 mg	AlTio2 75mg
		INJT CA 23^0 BTDC		
B20	CR16			
	CR17			
	CR18			
B30	CR16			
	CR17			
	CR18			
B100	CR16			
	CR17			
	CR18			

Table 1 Overview of Experimentation

C. *Details of the Test Rig*

Type of Engine	Single Cylinder 4-Stroke, Vertical engine
Rated Power	3.50 kW @1500 RPM
Compression Ratio Range	15.00 to 21.00
Cooling	Water cooled
Engine Specifications	Cylinder Bore 87.50(mm), Stroke Length 110.00(mm), Connecting Rod length 234.00(mm)
Dynamometer	Electrical Dynamometer

Table 2 Engine Specifications

III. RESULTS & DISCUSSION

A. *Performance Analysis*

Compression ratio is the ratio of maximum cylinder volume to the minimum cylinder volume. When the compression ratio increases the inducted air being compressed more and more during compression stroke and cause for the production of high compressed air with temperature. This air will help for proper atomization and mixing with the air, as a results proper combustion is done

CR/INJ	FUEL BLEND/Load	Bthe(%) 1 N m	6 N m	11 N m	17 N m	22 N m	BSFC(Kg/kWh) 1 N m	6 N m	11 N m	17 N m	22 N m	ME(%) 1 N m	6 N m	11 N m	17 N m	22 N m
CR16	B0	2.82	12.64	19.52	23.64	25.97	3.06	0.67	0.44	0.35	0.33	5.8	28.21	45.28	57.0	64.94
	B10	2.12	12.55	17.96	21.70	24.05	4.08	0.75	0.48	0.39	0.36	6.0	26.72	42.07	53.1	60.52
	B20	2.96	13.7	19.37	23.04	24.3	2.92	0.63	0.49	0.39	0.36	5.9	28.57	41.87	53.2	59.39
	B30	1.62	11.3	17.53	21.9	23.52	5.32	0.77	0.49	0.4	0.37	3.3	23.79	38.6	50.4	58.18
	B100	0.98	11.71	17.42	22.64	23.09	8.79	0.8	0.5	0.41	0.37	2.4	26.66	42.59	52.8	59.35
CR17	B0	2.82	12.64	19.52	23.34	25.97	3.06	0.67	0.44	0.36	0.33	5.8	28.52	45.28	58.3	64.94
	B10	1.19	12.24	19.05	22.35	24.79	3.26	0.7	0.45	0.38	0.35	2.4	26.78	42.85	52.4	59.89
	B20	2.5	14.29	19.07	23.63	25.17	3.45	0.6	0.45	0.36	0.34	4.5	27.8	40.85	52.4	59.36
	B30	0.43	12.5	17.97	23.31	25.29	3.2	0.7	0.48	0.37	0.34	3.1	26.37	39.15	51.5	58.04
	B100	1.47	12.95	18.36	23.21	24.07	3.89	0.71	0.47	0.38	0.36	3.1	27.21	42.93	53.8	60.14
CR18	B0	2.82	12.78	19.52	23.88	25.97	3.06	0.67	0.44	0.35	0.33	5.8	28.8	45.28	57.4	64.94
	B10	1.14	12.74	19.9	23.88	26.61	2.9	0.67	0.43	0.36	0.32	2.3	26.74	41.37	50.5	58.85
	B20	2.95	13.87	21.4	24.53	25.72	2.93	0.62	0.4	0.35	0.34	5.61	26.49	42.01	52	58.69
	B30	1.07	13.81	19.87	23.55	25.49	3.1	0.63	0.43	0.37	0.34	1.9	25.69	40.85	50.7	58.04
	B100	1.34	15.13	21.15	26.23	26.39	3.0	0.61	0.41	0.35	0.33	2.4	28.48	42.19	52.6	59.51
Injection Timing (B10 CR18)	INJT CA 21^0 BTDC	1.75	12.5	20.97	21.73	26.48	4.99	0.74	0.42	0.38	0.33	3.35	26.61	40.96	52.2	58.35
	INJT CA 22^0 BTDC	1.70	13.2	19.99	22.62	27.38	5.07	0.69	0.43	0.36	0.32	2.88	26.92	40.19	50.6	58.05
	INJT CA 23^0 BTDC	2.21	13.86	19.70	23.45	26.33	3.91	0.72	0.44	0.36	0.33	4.26	26.52	41.08	51.2	58.61

Table 3 Engine output values

In the performance of the engine the parameters like Bthe, BSFC, ME were investigated. Table shows the Bthe, BSFC and ME values for Safflower bio diesel blends i.e. B0, B10, B20, B30 and B100 at the compression ratio of CR16, CR17, CR18. Fossil based Diesel fuel is a Hydrocarbon fuel, when the bio diesel is mixed with the diesel oxygen is also available in the fuel mixture and cause for proper combustion fuel and releases the maximum energy within the cylinder it is observed from the results, by increasing the compression ratio the Bthe is linearly increasing, BSFC is Decreasing and ME is with negligible deviations.

Bthe. The Bthe is the effectiveness of engine power w.r.t to the fuel energy. It is the ratio of Brake power to the Fuel consumption and calorific value of fuel.

$$Bthe = \frac{BP*3600*100}{Mfc*CV}$$

Bthe is the indication for the ability of combustion system and how efficiently fuel energy was converted in to Power

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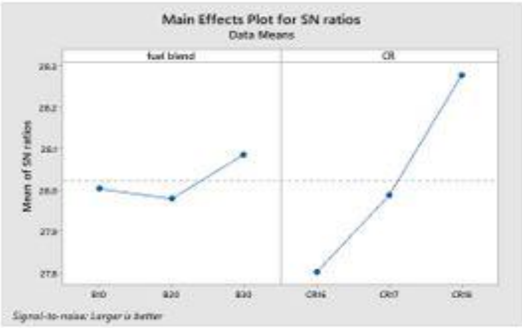
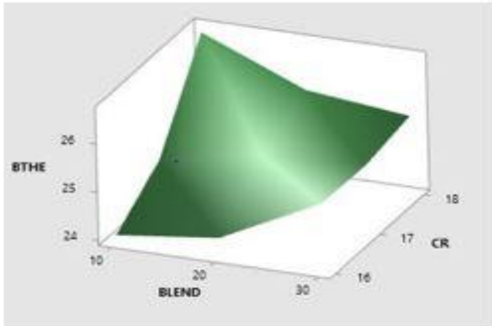
output (Brake Power) of the Engine. As the load on the engine increases Bthe is increased. Friction Power is the main parameter that will directly effects on brake power as well as Bthe..B10 and B20 blends are effective blends further increase in blend quantity leads to reduction in energy content and increase in fuel viscosity. This leads to reduction in Energy release rate and cause for reduction in Bthe. The combination B10 at a Compression Ratio of CR18 achieves a Bthe of 26.61%. at CR18 with an injection timing of INJR 22^0 BTDC achieves a maximum Bthe of 27.38%. whenever the injection timing is varied there is some more time period is available for proper mixing of fuel with the air and releases the maximum Mean effective pressure nearer to TDC. Further increase in injection timing leads to reduction in Bthe, the reason is whenever fuel releases into the combustion chamber proper atmosphere is required for evaporation and initiation of combustion. If the injection timing is advanced BTDC, the piston does not nearer to TDC, so Proper pressure and temperature atmosphere is not created leads to improper combustion and results in decreasing in Bthe.

Influence of Compression Ratio and Blends on Bthe





Source	DF	Seq SS	Adj SS	Adj MS	F	P
fuel blend	2	0.1465	0.1465	0.07323	0.18	0.839
CR	2	2.9249	2.9249	1.46243	3.67	0.125
Residual Error	4	1.5949	1.5949	0.39872		
Total	8	4.6662				

Fig 1 S/N Ratio, 3D Surface, ANOVA for Bthe

Minitab software is used for investigate the output. Following graphs represents the S/N ratio for two parameters, CR and fuel Blends. The parameter which have the minimum slope will influence the less on response. Like that the parameter which have the maximum slope (Max S/N Ratio) will influence the more on output response. From the plot, it is observed that compression ratio is the most influence parameter and it is varying linearly._By increasing the compression ratio, the response of S/N ratio is increasing linearly. The fuel blend B30 and CR 18 is the most influencing parameter on Bthe. It is observed that

Analysis of Variance (ANOVA) obtained by Taguchi method are tabulated in the table. The parameter which influence the most on Bthe is identified by evaluating the contribution. From the analysis it is observed that CR is the most Influencing parameter on Bthe.

To analyse the influence of the CR and Blend of fuel on Bthe, The 3D surface is plotted with Bthe against the CR and Blends. From the graph it is observed that the Bthe is decreasing with the increase in quantity of bio Diesel in the Blend, Bthe is Increasing with the increase in Compression Ratio. The maximum Bthe was obtained at B10 CR18.

BSFC

$$BSFC = \frac{Mfc}{BP} \text{ kg/kw}$$

is the consumption of fuel w.r.t the Brake Power. The BSFC is also called as Effective Fuel. The specific fuel consumption is decreases with increase in load. If The load on the engine increase causes increase in suction pressure, due to increase in suction pressure quantity of air in the cylinder is high, so enough oxygen for combustion of fuel is increased, proper combustion is takes plac**e.** by increasing the compression ratio, the BSFC is decreased. The combination B10 with a compression ratio of CR18 have a Minimum BSFC of 0.32 kg/kW-h.

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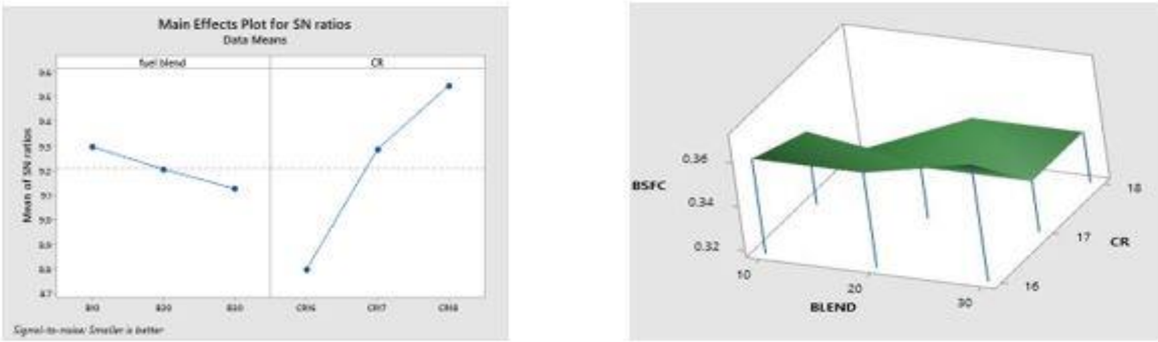
Influence of Compression Ratio and Blends on BSFC



Source	DF	Seq SS	Adj SS	Adj MS	F	P
fuel blend	2	0.000067	0.000067	0.000033	0.40	0.694
CR	2	0.001400	0.001400	0.000700	8.40	0.037
Residual Error	4	0.000333	0.000333	0.000083		
Total	8	0.001800				

Fig 2 S/N Ratio, 3D Surface, ANOVA for BSFC

From Fig 2, the S/N Ratio plot, it is observed that compression ratio is the most influence parameter on BSFC and it is varying linearly._By increasing the compression ratio, the response of S/N ratio is increasing linearly. The fuel blend B10 and CR 18 is the most influencing parameter on BSFC.

Analysis of Variance (ANOVA), it is observed that CR is the most Influencing parameter on BSFC.

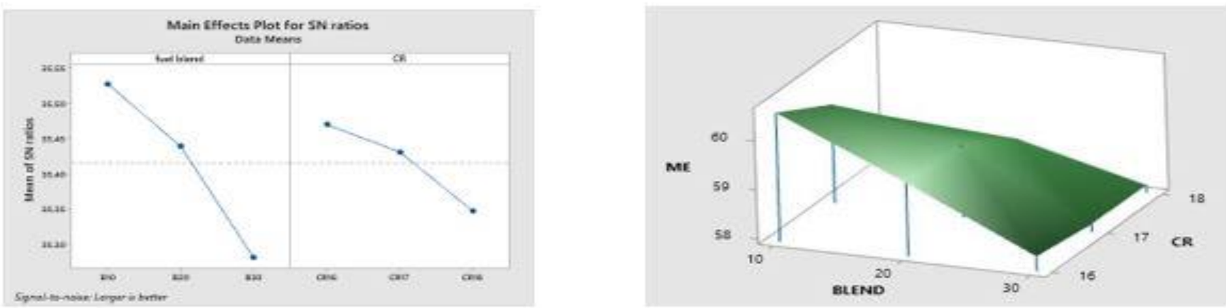
To analyse the influence of the CR and Blend of fuel on BSFC, The 3D surface is plotted with BSFC against the CR and Blends. From the graph it is observed that the BSFC is increasing with the increase in quantity of bio Diesel in the Blend, Bthe is decreasing with the increase in Compression Ratio. The minimum BSFC was obtained at B10 CR18.

ME is the Mechanical Efficiency. It is the relation between indicated power(IP) and Brake Power(BP).

$$ME = \left(\frac{BP}{IP}\right) * 100\%$$

The effectiveness in transformation for indicted power into Mechanical Power by means of Piston, Connecting rod and Crank shafts are indicated by ME. It is observed the by increasing the compression ratio the ME is reduced. At low compression ratios the engine is running smoothly by increasing the compression ratio the power is increased for operation of Fuel feed pump, Lubricating oil pump etc… leads to a negligible reduction in ME. The combination CR16 with B10 have a Maximum ME of 60.52%.

Influence of Compression Ratio and Blends on ME



Source	DF	Seq SS	Adj SS	Adj MS	F	P
fuel blend	2	4.2694	4.2694	2.1347	13.08	0.018
CR	2	1.0960	1.0960	0.5480	3.36	0.139
Residual Error	4	0.6528	0.6528	0.1632		
Total	8	6.0182				

Fig 3 S/N Ratio, 3D Surface, ANOVA for ME

From Fig 3, the S/N Ratio plot, it is observed that Fuel Blend is the most influence parameter on ME and it is varying linearly._By increasing the Bio Diesel quantity, the response of S/N ratio is decreasing linearly. The fuel blend B10 and CR 16 is the most influencing parameter on ME.

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Analysis of Variance (ANOVA), it is observed that Blend of the Fuel is the most Influencing parameter on ME.

To analyse the influence of the CR and Blend of fuel on ME, the 3D surface is plotted with ME against the CR and Blends. From the graph it is observed that the ME is Decreases with the increase in quantity of bio Diesel in the Blend, ME is decreasing with the increase in Compression Ratio. The maximum ME was obtained at B10 CR16.

From this experimentation the combination B10 with the compression ratio of CR18 at an injection timing of INJT CA 22^0 BTDC will be the best combination. Now for this Combination the Nano Additives like Cerium Oxide and Aluminum doped with Titanium oxide are added at a proportion of 25 mg, 50mg and 75mg. by considering the solubility range and viscosity the addition of nano additives is limited to 75mg.

		Bthe(%)					BSFC(Kg/kWh)					ME(%)				
Mode of Operation		1 N m	6 N m	11 N m	17 N m	22 N m	1 N m	6 N m	11 Nm	17 Nm	22 Nm	1 Nm	6 N m	11 N m	17 Nm	22 N m
B10 CR18	INJT CA 22^0 BTDC	1.70	13.2	19.99	22.62	27.38	5.07	0.69	0.43	0.36	0.32	2.88	26.92	40.19	50.6	58.05
Cerium Oxide	25 mg	1.2	13.4	20.81	24.49	27.14	7.21	0.64	0.42	0.35	0.32	2.05	25	40.82	50.78	58.23
CeO2	50 mg	3.25	15.27	21.49	24.48	26.37	2.66	0.56	0.4	0.35	0.33	5.21	27.5	41.79	51.26	58.27
(B10 CR18 INJT 22^O BTDC)	75 mg	1.96	14.14	20.73	25.02	28.13	4.41	0.61	0.42	0.34	0.31	3.29	26.58	41.27	51.66	59.06
Aluminium Doped with Titanium oxide	25 mg	0.66	14.35	21.5	27.52	32.37	6.2	0.6	0.4	0.31	0.27	1.2	26.57	40.7	50.86	58.49
AlTio2	50 mg	1.36	16.02	25.03	26.42	27.35	6.35	0.53	0.35	0.31	0.31	2.36	27.1	41.54	51.16	58.31
(B10 CR18 INJT 22^O BTDC)	75 mg	2.77	15.12	20.92	24.68	27.39	3.12	0.57	0.41	0.35	0.32	4.58	28.04	40.89	51.1	57.86

Table 4 Engine output Parameters for Nano Additives

Bthe it is observed from the table the addition of nano metal oxides to the fuel will increase the brake thermal efficiency. The Bthe for the operation B10 CR18 INJT CA 22^0 BTDC is 27.38% at a load of 22 N-m. the addition cerium oxide nano particles to this fuel i.e. B10 achieves a maximum Bthe of 28.13% with a quantity of 75mg. the addition of aluminium doped with titanium oxide is also increase the Bthe and it is about 27.52% at a quantity of 25mg, further increase in quantity leads to reduction on Bthe.

BSFC by the observation from the table by the addition of nano particles to the fuel. The addition of cerium oxide nano particles to the fuel is may not cause for a appreciable change in BSFC. But addition of aluminium doped with titanium may reduce the BSFC up to 0.27 kg/kW-h.

ME as discussed earlier the Mechanical efficiency is does not effected greatly by any kind of operation. The ME is about 58% with decimal deviations for all type of operations. The cerium oxide with a quantity of 75 mg achieves the maximum ME of 59.06%. the AlTiO2 with a Quantity of 25 mg achieves the maximum ME of 58.49%.

B Vibration Analysis

The Vibrations of the Engine Bed is captured by using 3 axis accelerometers (ADXL 335). It measures the G forces in X, Y and Z directions. The range of the accelerometer is 0.5Hz to 550Hz. The captured G forces are to be Collected and tabulated in a serial monitor by using Arduino UNO rev 3. The Vibrations is considered in the Hz and the maximum value of the vibration will be considered for the analysis part and tabulated at each and every experimentation.

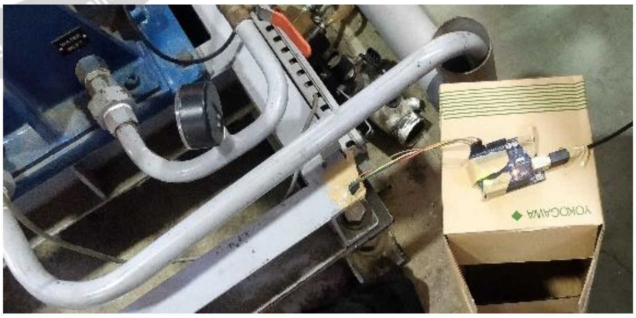

Fig 4 Vibration Measurement Setup

		Max Fx					Max Fy					Max Fz				
	FUEL BLEND/Load	1 N m	6 N m	11 N m	17 N m	22 N m	1 N m	6 N m	11 N m	17 N m	22 N m	1 N m	6 N m	11 N m	17 N m	22 N m
CR 16	B10	1.58	1.62	1.67	1.69	1.72	1.58	1.60	1.63	1.65	1.68	1.18	1.23	1.28	1.31	1.35
	B20	1.58	1.59	1.61	1.67	1.73	1.67	1.60	1.61	1.63	1.64	1.21	1.25	1.30	1.39	1.49
	B30	1.59	1.69	1.79	1.76	1.73	1.57	1.62	1.68	1.69	1.70	1.20	1.23	1.27	1.25	1.24
	B100	1.59	1.62	1.66	1.69	1.73	1.58	1.60	1.62	1.62	1.63	1.18	1.20	1.22	1.30	1.38
CR 17	B10	1.58	1.65	1.73	1.74	1.76	1.58	1.60	1.62	1.65	1.68	1.18	1.22	1.27	1.38	1.49
	B20	1.58	1.63	1.68	1.75	1.83	1.59	1.63	1.68	1.70	1.73	1.19	1.26	1.34	1.34	1.34
	B30	1.58	1.69	1.81	1.74	1.68	1.61	1.64	1.67	1.70	1.73	1.19	1.23	1.27	1.31	1.36
	B100	1.57	1.64	1.72	1.69	1.67	1.59	1.61	1.64	1.67	1.71	1.18	1.23	1.28	1.36	1.44

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CR 18	B10	1.61	1.69	1.77	1.77	1.78	1.61	1.62	1.64	1.65	1.67	1.22	1.31	1.40	1.49	1.58
	B20	1.59	1.66	1.73	1.75	1.77	1.60	1.62	1.65	1.67	1.69	1.21	1.25	1.29	1.40	1.52
	B30	1.62	1.70	1.79	1.78	1.77	1.61	1.69	1.78	1.71	1.64	1.24	1.23	1.23	1.22	1.22
	B100	1.61	1.64	1.67	1.75	1.84	1.62	1.62	1.63	1.67	1.71	1.22	1.27	1.33	1.47	1.61
Injection Timing (B10 CR18)	INJT CA 21^0 BTDC	1.61	1.68	1.76	1.79	1.82	1.62	1.62	1.63	1.64	1.65	1.20	1.31	1.42	1.48	1.54
	INJT CA 22^0 BTDC	1.60	1.73	1.86	1.84	1.82	1.59	1.61	1.63	1.68	1.73	1.21	1.32	1.44	1.57	1.70
	INJT CA 23^0 BTDC	1.58	1.71	1.84	1.80	1.77	1.58	1.60	1.62	1.64	1.67	1.21	1.33	1.46	1.52	1.58
Cerium Oxide	25 mg	1.62	1.67	1.73	1.77	1.82	1.61	1.64	1.67	1.67	1.68	1.21	1.29	1.37	1.46	1.55
	50 mg	1.58	1.63	1.68	1.74	1.81	1.59	1.61	1.63	1.66	1.69	1.21	1.28	1.35	1.40	1.45
	75 mg	1.60	1.61	1.62	1.70	1.79	1.60	1.64	1.68	1.69	1.71	1.22	1.30	1.38	1.46	1.54
Aluminium doped with titanium	25 mg	1.63	1.63	1.63	1.68	1.73	1.61	1.62	1.64	1.66	1.68	1.21	1.32	1.43	1.47	1.51
	50 mg	1.58	1.63	1.69	1.72	1.76	1.60	1.62	1.64	1.70	1.76	1.21	1.33	1.45	1.49	1.54
	75 mg	1.58	1.72	1.87	1.75	1.64	1.72	1.72	1.72	1.70	1.69	1.84	1.84	1.84	1.66	1.48

Table 5 Engine Bed Vibrations

It is observed from the vibration measurement, by increasing the compression ratio and blend percentage all directional vibrations are increasing. There is no appreciable change in the vibrations by changing the injection timing. Cerium oxide nano particles are not effecting on the vibrations. Aluminium doped with the titanium is also not effecting up to 50 mg further will increses the vibrations in all directions. The pure bio diesel (B100) is achieves the highest vibrations. The viscosity of the B100 is high compared to all other blends. So due to Viscosity poor atomization taking place then it will effects on the proper combustion of the fuel. Due to this reason pure mode have the highest vibrations.

IV. NOVELTY

- Safflower is used as a source for Bio Diesel.
- Experimentation is carried out with the both Engine & Fuel Modifications.
- Cerium Oxide, Aluminium Doped with the Titanium Oxide is used as a Nano Metal Oxide Additive.
- To observe the clear influence of the input parameter on the engine output the research is done with the Taguchi analysis, 3D surface Analysis and ANOVA Technique.
- Vibration analysis is done with the Accelerometer and Arduino UNO rev 3.

V. CONCLUSION

The present research reveals that safflower bio diesel is a quite alternate fuel to Fossil based Diesel duel. Compression Ratio is the most influence parameter on the engine Output. By increasing the bio diesel percentage in the fuel may reduces the all output parameters due to reduction in heating value and increase in viscosity. The addition of nano metal oxides will increase the Bthe and decreases the BSFC. The Combination B10 CR18 INJT CA 22^0 BTDC CeO2 75Mg, B10 CR18 INJT CA 22^0 BTDC AlTiO2 25Mg are the best combinations and suggested for the Stationary Engines.

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NOMENCLATURE

BTDC = Before Top Dead Centre
Bthe = Brake Thermal Efficiency
BSFC = Brake Specific Fuel Consumption
ME = Mechanical Efficiency
CA = Crank Angle
CR = Compression Ratio
INJT = Injection Timing
CeO2 = Cerium Oxide
AlTiO2 = Aluminum doped with Titanium Oxide
TDC = Top Dead Centre
B10 = (10% Bio Diesel + 90% Diesel)
B20 = (20% Bio Diesel + 80% Diesel)
B30 = (30% Bio Diesel + 70% Diesel)
B100 = (100% Bio Diesel)
B0 = (100% Diesel)

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