A REVIEW ON: EFFECT OF NANO-FUEL ADDITIVES ON DIESEL ENGINE

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Abstract : This Review paper shows the investigations performed by researchers using different Nano additives at variable operating conditions on the diesel engine. Researchers reports that by the addition of Nano particle additive in diesel and biodiesel there is improvement in the performance of the engine. For better performance and to decrease emissions optimum amount of Nano-additives, appropriate percentage of biodiesel in diesel is preferred. The demand of diesel is very high also it produces high pollutants like CO, HC, NO_x and PM. So as to improve the combustion and heat rate. Nano additives which are metal oxide particles when added to fuel, it affects fuel properties. It increases BTE (approx. 2-16 %) and decrease BSFC (approx. 1-15 %) by increasing combustion rate and decreasing ignition delay**.**

Keywords **- Performance, Emission, Nano Additives, Diesel and Biodiesel blends.**

I. INTRODUCTION

India is world's third largest oil consumer after US, china [1]. India depends on other countries for diesel. In India diesel consumption in transportation sector is 70%, agricultural sector is 13%, and other sector is 17% of total diesel consumption [2]. Day by day consumption and price of diesel is increasing. Petroleum product are very necessary to run our day to day activities. The requirement of diesel and other fuel is higher than its availability in India. The increase in the demand of the diesel because of enhancement in the use of diesel engine in the different applications and fields is making the increment in the value of the diesel therefore mostly petroleum products are imported from other country. The thermal efficiency and compression ratio of diesel engine is greater than that of petrol (SI) engine. But the main drawback is the diesel engine have higher emissions. Diesel produces the UBHC, HC, NO_x, CO and PM in large quantity, which is very harmful to environment and lot of side effect of these emission on human respiratory system, animals and plants.

From above, awareness about emission caused by diesel is created. So, biodiesel blends fulfil as substitute fuel which reducing emission. Biodiesel is cheap fuel and can be produced easily. There are lot of sources to get biodiesel, biodiesel are produce from jatropha by trance esterification similarly oil seed, biodegradable waste, plants, canola peanut, etc. Biodiesel have the properties such as high kinematic viscosity, oxygen content is higher, lower smoke emission [3]. Carbon emissions produced by the combustion of biodiesel is consumed by the plants in the process of photosynthesis, hence global warming decreases [4]. The performance characteristics of biodiesel is less, and its consumption is high. Experiment were conducted by using diesel and biodiesel composition (BDF20, BDF50, BDF1000) in diesel engine at different loads and constant speed 1800 rpm. Results shows that as proportion of biodiesel in diesel increases, CO_2 and NO_x emissions increases whereas CO and HC emissions decreases. Fuel consumption increases as biodiesel proportion in diesel increases [8]. Addition of Nano particle in the biodiesel or neat diesel causes change in the properties. The performance of the diesel engine increases by addition of Nano additive like copper oxide, cerium oxide, aluminium oxide etc., due to excess of oxygen in Nano additives the combustion rate increases. No significant changes are observed in viscosity, density and flash point of fuel due to addition of Nano additive such as zinc in diesel and biodiesel blends [4]. Al_2O_3 blend with biodiesel improved combustion characteristics and reduced carbon deposits in cylinder by 44.8% [10]. When diesel and biodiesel (methyl ester calophyllum and inophyllum crude oil) blends are added with cerium oxide then UBHC, CO, NO_x, and smoke emission were reduced. BTE increased by 3.21% and BSFC reduced by 11.7% [3]. When diesel and biodiesel (pongamia methyl ester) blends added with copper oxide then UBHC, CO, NO_x and smoke emission were reduced. BTE increased by 4.01% and BSFC reduced by 1.0% [13]. The addition of Ag and CNT Nano-particle in biodiesel affects combustion parameters of diesel engine. Result of adding two Nano-additives in biodiesel separately showed that rate of rise of maximum pressure increases as compared to pure diesel due to shorter ignition delay [9].

1.1 Objective Of The Paper

The main purpose of this review paper is to spread the knowledge, information to automotive researchers, students, and industry people. The review paper shows the information of the studied papers in the collective and summarized manner for the further research in the field of Nano-fuel additives for diesel engine operated with diesel/biodiesel blends. Literatures are reviewed from recent publications.

II. FUEL PROPERTIES WITH ADDITION OF NANO ADDITIVES

The changes and the effects due to addition of nano additives in the diesel and biodiesel blend is shown in this section. Comparative values are shown in Table 1.

2.1 Effect On Density, Flash Point And Viscosity

Effect of nano-fuel additive and other additive on density, flash point & viscosity is shown in the section. The viscosity affects the fuel atomization. Addition of the TiO_2 in the diesel and biodiesel blend increased the kinematic viscosity than euro diesel [5]. But addition of butanol decreases the kinematic viscosity than the TiO_2 added blends. Addition of TiO_2 increased the flash point and addition of butanol decreased the flash point. No significant change in the density is observed [5]. H. Suresh Babu Rao [3]

observed that addition of cerium oxide (CeO_2) increased the kinematic viscosity, flash point and density. Addition of biodiesel amount in diesel increases density, kinematic viscosity [8]. Addition of CNT and Ag in biodiesel increases density, viscosity [9]. As proportion of Al_2O_3 in B20 increases specific gravity, kinematic viscosity increases [10]. The combustion quality increases and heating value decreases with oxygen content. The content oxygen is about 13% by mass in biodiesel and positive effect on combustion process is seen with the addition of MWCNTs to JB20D [12]. In addition of zinc oxide Nano particle with the biodiesel and diesel blends , it was observed little bit enhancement in kinematic viscosity, flash point compared with composition A20[14].

2.2 Effect On Calorific Value, Cetane Number

Effect of addition of nano additives on calorific value and cetane number is discussed here. The calorific value of the cerium oxide (CeO_2) added blends is higher than that of diesel/biodiesel blend but less than the diesel [3]. When only TiO_2 is added heating value becomes greater than diesel/biodiesel and butanol blends but less than diesel [5]. Addition of CNT and Ag in biodiesel increases heating value and Cetane number [9]. Increment in proportion of Al_2O_3 in B20 increases, specific gravity, kinematic viscosity, calorific value increases [10]. Ignition delay decreases with increases in cetane number. The cetane number is increases about 5% for JB20 blends compare to the diesel fuel and addition of Nano additive to JB20D blends the cetane number reach to 8% [12]. When there is Increase in calorific value, it is observed that there is less specific consumption and greater viscosity tends to less atomization [14].

Table 1 : Various Properties Of Fuel And Nano Additives Used In Diesel Engine

Reference	Fuel	Properties				
		Kinematic Viscosity (cst)	Flash point (^{0}C)	Calorific value/Heating value(kJ/kg)	Density (g/cm^3)	Cetane number
[3]	Diesel	2.4	46	42534	835(kg/m^3)	-
	CI20	3.47	49	41342	858(kg/m^3)	-
	CI20+30ppm	3.58	52	41402	862(kg/m^3)	-
[9]	Diesel	4.24(mm^2/s)	-	45720	835(kg/m^3)	46
	BD+Ag40	4.36(mm^2/s)	-	46440	854.7(kg/m^3)	47
	BD+CNT40	4.74(mm^2/s)	-	47120	879.9(kg/m^3)	57
[13]	Diesel	2.65	56	45.25(MJ/kg)	810(kg/m^3)	-
	B20	3.02	69	43.68(MJ/kg)	824(kg/m^3)	-
	B20CuO50	4.79	67	43.78(MJ/kg)	835(kg/m^3)	-
[14]	Diesel	4.0	50	43200	830 (kg/m^3)	46.4
	AOME	5.18	76	39575	880.2(kg/m^3)	7.19
	D80A20	3.8	52	42475	835(kg/m^3)	54
	D80A20ZnO50	3.9	53	42723	836(kg/m^3)	57

III. Engine Performance Characteristics

This section reports effect of various fuel combinations on performance characteristics particularly BSFC, BTE of diesel engine. Effect of fuel combinations on performance of diesel engine is shown in Table 2.

3.1 Effect On Brake Specific Fuel Consumption

Brake specific fuel consumption is the amount of fuel required to produce brake power. It can be defined as the mass flow rate of fuel per unit brake power developed. H. Suresh Babu Rao [3] investigated that with the addition of the cerium oxide (CeO_2) the brake specific fuel consumption decreases. The addition of cerium oxide (CeO_2) buffers the oxygen and improve the combustion. Also by increasing CR helps to reduce ignition delay & improve combustion rate, which ultimately decreases the BSFC. I. Örs [5] investigated that BSFC by the addition of the butanol in diesel/biodiesel blend increases. As addition of butanol increases the oxygen content (by weight) and also decreases the calorific value hence ultimately leads to higher BSFC. But due addition of TiO_2 combustion rate increases with increase in calorific value hence BSFC decreases due to addition of TiO_2. Mohit Raj Saxena [6] investigated that at optimized condition the increment in the butanol in diesel blends increases the BSFC because of less energy content in butanol. Hossein et al. [7] investigated that BSFC decreases by increasing CeO_2 Nano particles. Hakan et al. [8] observed that fuel consumption increases as biodiesel percentage in diesel increases. Lowest BSFC obtained for 20% biodiesel proportion in diesel. G. Najafi [9] studied effect of CNT and Ag Nano additives in biodiesel. Study showed that fuel consumption decreases as proportion of CNT and Ag in biodiesel increases when added separately. For 120 ppm dosing level of CNT in biodiesel lowest BSFC 210 g/Kw-hr was observed. Mahalingam. S and Ganesan. S [10] used Al_2O_3 Nano particles in B20. As dosing level of Al_2O_3 in B20 increases, BSFC increases because of higher viscosity and lower heating value of biodiesel. For 10ppm dosing level of Nano additives in B20 gives BSFC very close to pure diesel.

The main parameter that affect the BSFC is combustion quality. The addition of MWCNTs improve the engine performance. It can be show that the engine brake specific fuel consumption using JB20D slightly increases by about 12% by comparing with the pure diesel [12]. Low BSFC 202.96g/kw-h was observed for BD-CNT120 blend than neat diesel [11]. When 100 ppm Cuo is doped with diesel and biodiesel blend, BSFC is decreased by 1.0% [13]. When zinc oxide is doped in the blends of diesel and biodiesel in proportion of 100ppm then BSFC is decreased by 3.82 % [14]. When CuO is added with blends of diesel and biodiesel BSFC is reduced [15].

3.2 Effect On Brake Thermal Efficiency

Addition of the Nano additive increases the calorific value, reduces the ignition delay and leads to the complete combustion. Also it helps to achieve high temperature which leads to the high BTE. H. Suresh Babu Rao [3] shown that by the addition of cerium oxide (CeO_2) leads to the increase in the BTE as the concentration of the (CeO_2) increases for the CR=20 and 100% load. This happens because of increment in compression ratio. I. Örs [5] stated that by the addition of the butanol the BP of engine decreases as calorific decreases. Addition of the TiO_2 help to complete the combustion, also increase calorific value and hence increases the BP & Brake Torque. Mohit Raj Saxena [6] stated that due to increase in concentration of butanol at optimized condition (CR=18, IP=200 bar, 100% load) BTE of engine decreases. As proportion of Ag and CNT Nano particles in biodiesel increases, average power increases [9]. If the amount of Nano additives increases, BTE decreases due to higher viscosity, higher density and lower heating value biofuel leading to poor atomization and vaporization. At full load condition, Maximum 22% BTE was observed for 10ppm Nano additive in B20 [10].

The highest BP is obtaining at 2.03% for CNT120-D80-B20 blends whereas it is 1.84% for CNT120. The highest BP is obtain as 2% for CNT120-BD [11]. When 100ppm dosing level of CuO is added with diesel and biodiesel blends, the BTE is increased by 4.01% [13]. ZnO is added in the blends of Diesel and Biodiesel BTE is Increases by 2.79 % [14]. If CuO is added in the blends of Diesel and Biodiesel, then BTE is increased by 1.3 % [15].

Table 2 : Overview Analysis Of Engine Performance And Emissions Using Nano Fuel And Other Additives In Diesel And Biodiesel

Base Fuel	Engine	Operating Conditions	Nano Fluid Additive	Composition	Performance Results	Emission Results	Refer-Ence
Biodiesel (Methyl Ester) / Neat Diesel	1-cylinder, 4-stroke	CR=16-20, Load=100%, IP=200 bar, 1600 rpm	Cerium oxide(CeO_2)	30 ppm 60 ppm 90 ppm	Increase in BTE, Decrease in BSFC	UBHC decreases, CO decreases, NO_x, smoke emission reduced	[3]
Euro Diesel	1-cylinder ,4-stroke, WC,DI	CR=17.5,Injection pressure=190 bar,1400 & 2800 rpm	Biodiesel(waste cooking oil methyl ester) +Butanol+TiO_2	-	Decrease in BP, Decrease in BSFC	CO reduced, HC reduced, NO increased, smoke opacity reduced	[5]
Diesel (2% sorbitan oleate)	6-cylinder ,4-stroke, air cooled	CR-16:1, different engine speed from 1300-1900 rpm	cerium oxide	10, 20, 40 ppm	Decrease in BSFC	Reduction in NO_x, HC & slight increase in CO compared to pure diesel	[7]
Diesel	4-cylinder, 3L, turbocharge,intercooled,WC	CR-17.5:1, different loads	biodiesel - waste cooking oil	20%, 50%, 100%	Increase in BSFC	Increase of biodiesel in diesel increases CO_2, NO_x and CO, HC decreases at full load	[8]
Diesel	1-cylinder ,4-stroke, air cooled	CR-17.5:1, IP-220 bar, 1500 rpm, different loads	biodiesel - esterified rubber seed oil, Al_2O_3	10,15,20 ppm	Decrease in BTE, Increase in BSFC	NO_x decreased and CO, HC increased.	[10]
Diesel	6-cylinder, 4-stroke	Full load condition, CR=17:1	Carbon Nano tube /Ag	40,80,120 PPM	Increase brake power, Decrease BSFC	NO_x ,CO_2 increases & UHC, CO decreases	[11]
Jojoba methyl ester	1-cylinder ,CI-engine	At different load condition	Multiwall carbon Nano tubes	10,20,30,40 ,50 Mg/l	Increase BTE, Decrease BSFC	NO_x decreases Co decreases UHC decreases	[12]
Neat diesel / Biodiesel (Pongamia methyl ester)	4-stroke single cylinder (Kirloskar engine)	CR=12-20,IP=200 bar, 1500 rpm, different loads	CuO	100 ppm	BTE Increase BSFC Decrease	UBHC less than Diesel, CO reduced, NO_x reduced, Smoke emission reduced	[13]
Neat diesel/ Biodiesel (Annona oil methyl ester)	4-stroke 1-cylinder engine (Kirloskar engine)	CR=17.5, IP= 200 bar, 1800 rpm, different loads	ZnO (Zinc oxide)	50 ppm 100 ppm	BTE Increase BSFC Decrease	UBHC Decrease, CO Decrease, NO_x Decrease Smoke emission Decrease	[14]

IV. Engine Emission Characteristics

The diesel fuel causes high environment harmful emissions which should be control to follow the Norms. The comparative and summarized study of the performance and emission characteristics of various researches given in the Table 2 and 3. Values of various parameters are taken from the graphs and conclusions of respective papers.

4.1 Effect On Hydrocarbon (HC) Emission

When fuel enters into the combustion chamber which is not burn properly, due to incomplete combustion of hydrocarbon content in form of exhaust comes into atmosphere which is very harmful for environment such as human, plants, and animals. So, with diesel and biodiesel blends Nanoparticle is added to reduce the level of hydrocarbon pollutant. In diesel and biodiesel blends added the CeO_2 and CuO Nano additive to reduce the level of pollutants. Because CeO_2 and CuO is acts as oxygen buffer catalyst. In diesel and biodiesel blends if add CuO Nano additive in the composition of B20+CuO100 which may decreases the UBHC emission by 7.9% [13] Which is less than neat diesel. On the other hand, in diesel and biodiesel blends added the CeO_2 Nano additive in the composition of B20+30ppm, B20+60ppm, B20+90ppm, and UBHC emission is reduced to 43ppm, 42ppm, 40ppm respectively [3]. When Diesel is added with Annona Biodiesel and Zinc oxide is added in that mixture then UBHC is decreased by 4.76% [14]. Similarly when copper oxide is added with mahua methyl ester and diesel blends UBHC is decreased by 75ppm [15]. Addition of TiO_2 in the blends of diesel, biodiesel and butanol leads to the decrease in the HC formation as it also helps to complete combustion [5]. When butanol added into the diesel it increases the HC emission because of high heat of vaporisation and high ignition delay [6]. As concentration of CeO_2 in diesel increases HC emissions increases [7]. At full load condition as percentage of biodiesel in diesel increases HC emissions decreases than pure diesel [8]. As proportion of CNT in biodiesel increases HC emissions increases. When Ag proportion increases in biodiesel HC emissions decreases [9]. At full load condition as proportion of Al_2O_3 in B20 increases HC emissions [10]. The concentration of HC emission decreases with the increase with relative air fuel ratio. If Nano silver particle added in biodiesel it will decrease the HC emission. The highest decrease for hydrocarbon is observed as 28.56% for Ag120-BD blends [11]. Using the JB20D led to considerable increase in hydrocarbon compared to the pure diesel [12].

4.2 Effect On NO_x Emission

When CuO Nano-additive are added with diesel and Biodiesel blends, there is decrease in the NO_x emission. In diesel and biodiesel blends doping with CuO Nano additive with composition of B20+CuO100 ppm which may decrease NO_x emission by 9.8% than neat diesel [13]. Now, in diesel and biodiesel blends doping with CeO_2 Nano-fuel additive with composition of 30ppm, 60ppm and 90ppm then NO_x is reduce to 1200 ppm, 1180ppm, 1160ppm. The nitric oxide (NO) and nitrogen dioxide (NO_2) is generally forms due to high temperature, high combustion rate and oxygen excess [3]. Due to addition of CeO_2 in diesel/biodiesel blends there is decrement in the NO_x formation [3]. In diesel and biodiesel blends if the Zinc oxide Nano additive is added in 50 ppm and 60 ppm then NO_x emission is decreased by 3.82% [14] and on the other hand in same blend if we added the Nano additive of copper oxide in 50 ppm then in that cases NO_x is increases by 800ppm [15]. As concentration of CeO_2 in diesel increases NO_x emissions decreases [7]. At full load condition when biodiesel percentage increases in diesel NO_x emissions increases [8]. As proportion of CNT in biodiesel increases NO_x emissions increases. When Ag proportion increases in biodiesel NO_x emissions increases [9]. At full load condition as proportion of Al_2O_3 in B20 increases, NO_x emission decreases [10]. The addition of oxygenated additives in blends results into increased combustion with longer ignition delay. The value of the NO_x at 1000rpm is 1300ppm for pure diesel and for diesel +Ag40 it is 1600ppm [11]. To decrease this emission various metal additive such as MnO and CuO are added [4]. This additive mixed with diesel results in complete combustion and reduced exhaust gaseous. The addition of the MWCNTs to JB20D led decrease in NO_x compare to the JB40D blends [12].

4.3 Effect On Carbon Monoxide (CO) Emission

From literature survey information about carbon monoxide collected. It is colourless gas where density is slightly less compared to air [16]. However in vehicle Air-fuel mixture is rich mixture due to this rich mixture carbon monoxide are produced which is very harmful for environment. The factors influence for CO emission such as injection pressure, engine speed, Air-fuel ratio etc. This emission is reduced when Nano particle is doped in blends of diesel and biodiesel. So, in diesel and biodiesel blends if CuO Nano-fuel particle is added in the composition of B20+CuO100 which may decrease the CO emission by 29% than the neat diesel [13]. In diesel and biodiesel blends if CeO_2 Nano-fuel additive is added in composition of 30ppm, 60ppm, and 90ppm then CO emission is decrease to 0.22%, 0.19% and 0.18% respectively [3]. When in blends of diesel and biodiesel if zinc oxide Nano additives added then carbon monoxide emission is decreased by 14.75 % [14] and similarly when copper monoxide is added with blends in such case CO emission is decreased by 0.12% [15]. The addition of TiO_2 in the blends of diesel, biodiesel and butanol causes to increases in the surface area which leads to complete combustion [5]. There is decrease in CO formation but increment in the CO_2 formation due to complete combustion. At higher load condition addition of butanol causes the reduction in CO formation but at low load due to high heat of vaporisation CO emission increases when the concentration of butanol increases [6]. As concentration of CeO_2 in diesel increases, CO emissions slightly increased compared to pure diesel [7]. At full load condition when biodiesel percentage increases in diesel, CO emissions increased [8]. As proportion of CNT in biodiesel increases, CO emissions decreases as compared to pure diesel. When Ag proportion increases in biodiesel, CO emissions decreases [9]. At full load condition as proportion of Al_2O_3 in B20 increases CO emissions increases [10]. The addition of silver particles and carbon Nano tubes further decrease the CO emission. But using JB20D led carbon monoxide (CO) increases. At high rpm that is at 1000 rpm for pure diesel the value for carbon monoxide is 1.4(%V). And for CNT80 is 1.2(%V) [11]. This value is varies with different engine speed. Using the JB20D additive the carbon monoxide considerable increases [12].

4.4 Effect On Smoke Opacity And Total Particulate Number (PN)

Due to poor combustion smoke produced is very black. Which effects on engine speed, load and rating of fuel. When CuO is added with diesel and biodiesel smoke emission is reduce by 12.8% for composition of B20+CuO100ppm [13]. CeO_2 is added with diesel and biodiesel smoke emission is reduce to 75%, 72%, and 70% for composition of 30ppm, 60ppm, and 90ppm [3]. In diesel and biodiesel blend if the zinc oxide Nano additive is added with composition of 100ppm then smoke emission is decreased by 7.14 % [14]. When in blend (100MEOM + 50ppm) the copper oxide Nano additive with composition of 50 ppm then smoke emission is decreased by 80 ppm [15]. There is significant decrease in smoke opacity with the addition of both butanol and TiO_2 in the diesel/biodiesel blends [5]. When there is addition of butanol diesel at 25% and 50% load almost 90% decrease in the particulate number (PN) is seen and at higher load 20% reduction is seen [6].

Table 3 : Detail analysis of performance and emission characteristics

Reference	Nano Additive /Base Fuel	Concentration (ppm)	BSFC (Kg/kW-hr)	BTE (%)	NO_x (ppm)	HC/ UBHC (ppm)	CO	Total PN / CO_2	Smoke Opacity Emission
[3]	CeO_2 / Biodiesel, Diesel	30 60 90 } %	12.7 12.1 11.7 } %	3.63 3.4 3.21	1200 1180 1160	57 43 40	0.23 0.2 0.18 } %	- - -	75 72 70 } %
[5]	TiO_2/ Biodiesel+ Butanol, Diesel	-	-17.89%	**BP:** -2.31	+1.20%	-34.39%	-38.09%	-	-39.18%
[6]	Butanol /Neat Diesel	10 20 30 } %	0.3 0.32 0.34	29 28 27	1150 950 900	320 330 250	0.025 0.02 0.01 } %v	1.7 1.9 1.6 } *10^8 (/cm^3)	- - -
[8]	biodiesel – waste cooking oil /Diesel	20 50 100 } %	0.221 0.226 0.236	-	5.262 5.497 5.988 } g/kwh	0.045 0.035 0.017 } g/kwh	0.167 0.166 0.138 } g/kwh	704.6 719.8 753.6 } g/kwh	-
[9]	Ag /Diesel, biodiesel-methyl ester	40 80 120	0.221 0.217 0.215	-	1620 1650 1700	16 15 14	1.55 1.5 1.45 } %v	10.2 10.25 10.5 } %v	-
[10]	Al_2O_3/ Diesel, biodiesel – esterified rubber seed oil	10 15 20	0.38 0.385 0.42	22 21 20	966 883 800	27 29 34	0.07 0.08 0.12 } %v	-	-
[11]	Carbon Nano tube & Ag / Diesel	40 80 120	-7.08% (CNT120 /ppm)	-	+25.32% (CNT / 120 ppm)	-28.56% (Ag / 120 ppm)	-25.17% (CNT / 120 ppm)	-	-
[12]	MWCNT /jojoba methyl ester	10,20,30, 40,50 Mg/l	-15% (50 Mg/l)	+16% (50 Mg/l)	-35% (40 Mg/l)	-60% (40 Mg/l)	-50% (40 Mg/l)	-	-
[13]	CuO / pongamia methyl ester	100 ppm	-1.0 %	+4.01%	9.8 % reduced than B20	7.9 % less than Diesel	29 % reduced than Diesel	-	12.8% decrease
[14]	Zinc oxide/Annona oil methyl ester	100 ppm	-3.82 %	+2.79 %	3.82 % Decrease	4.76 % Decrease	14.75 % Decrease	-	7.14 % Decrease

V. CONCLUSION

From the investigations carried out by various researchers, it is observed that nano-fuel additives helps to improve the overall performance and emission characteristics of the diesel engine. It improves the combustion, also increase the reacting surface area. Following are the conclusion drawn from the researches:

- Brake specific fuel consumption is decreased with addition of nano fuel because of high combustion rate and decrement in the ignition delay.
- Brake thermal efficiency is much improved with addition of nano fuel additives because of quick combustion starting, high calorific value, high oxidation and achievement of high temperature.
- Biodiesel fuel have more oxygen and less carbon molecule compared to diesel. Hence emission of CO_2 and NO_x of biodiesel are higher than diesel fuel.
- Diesel fuel have more carbon and less oxygen molecule compared to biodiesel. Hence emission from diesel of CO and HC are higher than biodiesel fuel.
- The NO_x, UHC, and CO emission were remarkably reduced with the addition of MWCNTs into the JB20D.The best combustion characteristics of the engine was obtaining at a Nano additive doping level of 50mg/l.
- Among the all investigated Nano additives CuO is better and effective.
- Brake thermal efficiency is improved by 4.01 % with addition of CuO Nano fuel additives in pongamia methyl ester.
- Emissions are decreased due addition of CuO Nano additives. CO (29%), HC (7.9%), NO_x (9.8%), smoke opacity are reduced respectively.

- ❖ CuO Nano particle blended in pongamia biodiesel can be adopted as a replace fuel in diesel engine for complete green environment.

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