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NANO FUELS: EFFECTIVE ALTERNATIVE TO DIESEL FOR CI ENGINE

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Abstract— Central objective of this review paper is to encapsulate findings to have viable alternative to diesel as main working medium in Compression Ignition Engine. Various investigations on biodiesel were succeeded in order to diminish burden on consumption of diesel but due to lesser thermal efficiency and emission characteristic of divers blends could not achieve at par results with neat diesel. Advancement in Nano-technology and successful results of Nano particle in varied fields seek attention of researchers and engineers to include Nano particle in diesel blending. This study represents overview and results on experimental investigation to examine the effect of Nano additives on diesel engine performance at variable operating conditions of loads and speeds. Use of Cerium Oxide, Alumina Oxide, Carbon nano tube and other are used for experimentation. Water emulsion blends also tested with neat diesel and nano fuels. Advertently it can be seen that improvement in brake thermal efficiency (BTE) is increased by 1-2%. Reduction in major pollutant such as NOx, CO, HC has been achieved. Brake specific fuel consumption (BSFC) was reduced by marginal amount.

Keywords—Nano particle; Cerium Oxide; Alumina Oxide; Carbon nano tube;BTE, BSFC; emulsion;NOx;CO;HC

I. INTRODUCTION

Internal combustion engine are prime source of power in automotive industry and other industries. Diesel engines are widely used in industry. Worldwide consumption of diesel alone is 91,190,000bbl/day with India standing on fourth rank with 3,660,000 bbl/day[22]. Many researches are being carried to change in fuel properties to enhance the properties of diesel. Alsoadditives are proven to meet performance of diesel engine. It is known fact that fossilfuel resources are depleting day by day and hence, there is a need to search for alternative fuels to fulfill the growing energy demands of the world. More importantly, the environmental crises caused by vast combustion of fossil fuels have also led researchers towards finding strategies to address the critically worrying level of air pollution and its potentially tragic consequences e.g., climate change [2]. Among the various alternative fuelshave received a great deal of attention as the most desirable fuel extenders for the transportation sector. Because of its reproducibility, nontoxicity, and sulfur free, biodiesel is considered as a potential alternative fuel of diesel fuel. Furthermore, due to its similar properties to diesel fuel. Biodiesel can be produced from vegetable oils as well as animal fats. It is advisable to use non-edible vegetable oil than edible oils reason being edible oils is used for food production and non-edible oils are not suitable for human consumptions [20]. Formation of NOx is point of concern while operating on diesel or biodiesel. Combustion of diesel or bio diesel in CI engine resulted in high temperature leading to NO is formation, which is hazardous gas to the environment because NO can react with oxygen present in the combustion chamber which result in the formation of NO_2.

Combination of NO and NO_2 give rise to formation of NOx. Many researchers investigated various biodiesel blends in order to improve upon overall efficiency and reduction in pollutants. To overcome problems raised by diesel and biodiesel, nano size metal particles are investigated. Due to small particle size, shortened ignition delay, improvement in oxidation and decreased burn time was observed heading towards complete combustion of fuel [21].

Objectives of review paper

This paper provides a cumulative idea of nano particles blended with diesel in various proportions. Results discussed here may find helpful for researchers, engineers and other aspirants in the field of alternative fuels. Some of water emulsion results are being compiled which might give good comparison between diesel, biodiesel, emulsion and nano fuel. Detailed discussion in made on physical characteristics, performance and emission characteristics of fuels.

II. Effect of nanofluid additives on fuel properties

Physical properties of diesel when compared to Nano additives blends prepared shown other values than neat diesel. All the researchers have studied the physical properties of diesel, emulsion and nano additives with standard ASTM procedures.

a) Effect on Density, flash point and viscosity

Sadhikbasha et al[1] prepared water-diesel emulsion fuel and blended with Alumina particle, which resulted into high density and kinematic viscosity of mixture as compared to neat diesel. C.S. Aalam et al.[2] studied morphological characteristics of Aluminum nano particles with scanning electron microscopy. Methyl ester when added with Aluminum nano particle (ANP) showed

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increase in viscosity, density also flash point value was noticeable. Addition of ANP in the range of 50-100 ppm would result in decrease in density. Soyabean biodiesel blend with 20% soyabean and 80% diesel was prepared by T Shaafi et.al [3] and infuse other blends with 80% diesel, 15% soyabean, 4% ethanol and 1% isopropanaol as surfactant and alumina nano particles of 100mg/lit. This recorded viscosity as more for soyabean and that of diesel. A Kenskin et al[8] worked with Palladium and Nickel dopedas 50 ppm and 100 ppm into diesel fuel did not show any significant change in density and calorific value except for marginal increase in flash point which is maximum for N100 indicating storage of fuel more s

TABLE 1 :NOMENCLATURE

Bbl/day	Barrels per day	ANP	Aluminum nano particle
BSFC	Brake specific fuel consumption	D2S15W	Diesel(83%) Surfactant(2%) Water(15%)
BTE	Brake Thermal Efficiency	D2S15W25A	Diesel(83%) Surfactant(2%) Water(15%) Alumina(25 ppm)
CI	Compression Ignition	D2S15W50A	Diesel(83%) Surfactant(2%) Water(15%) Alumina(50 ppm)
CO	Carbon mono oxide	D2S15W100A	Diesel(83%) Surfactant(2%) Water(15%) Alumina(100 ppm)
CO_2	Carbon di oxide	MME20	Mehua Methyl Ester(20%) ,Diesel(80%)
NOx	Oxides of Carbon	MME20+ANP50	Mehua Methyl Ester(20%) ,Diesel(80%),Alumina(50 ppm)
NO_2	Nitrogen di oxide	MME20+ANP100	Mehua Methyl Ester(20%) ,Diesel(80%) ,Alumina (100 ppm)
HC	Hydrocarbon	B20	80% diesel, 20% Soybean
AC	Air cooled	D80SBD15E4S1 + alumina	80%diesel, 15%soybean,4%ethanol,1%isopropanol, Alumina 100mg/L
DI	Direct Injected	JBD5A5C	Alumina 5 ppm and Cerium 5 ppm
IT	Ignition timing	JBD15A15C	Alumina 15 ppm and Cerium 15 ppm
RET IT	Retarded Ignition timing	JBD30A30C	Alumina 30 ppm and Cerium 30 ppm
ADV IT	Advanced Ignition timing	Methyl Ester(B20)	80% Diesel ,20% PSWME
W	Water	D80B20ZnO50	80% Diesel ,20% PSWME ,50 ppm Zic Oxide
D	Diesel	D80B20ZnO100	80% Diesel ,20% PSWME ,100 ppm Zic Oxide
MnO	200 mg of MnO in 1L of diesel	P50	PdL_2 50 ppm
DCuO	200 mg of MnO in 1L of diesel	P100	PdL_2 100 ppm
JB20D	80% Diesel ,20% by vol.Jojoba	N50	NiL_2 50 ppm
JB20D10A	80% Diesel , 20% by vol.Jojoba ,10 mg/l	N100	NiL_2 100 ppm
JB20D20A	80% Diesel ,20% by vol.Jojoba ,20 mg/l	JBD	Jatropha biodiesel
JB20D30A	80% Diesel ,20% by vol.Jojoba ,30 mg/l	JBD25A	25 ppm alumina
JB20D40A	80% Diesel ,20% by vol.Jojoba ,40 mg/l	JBD50A	50 ppm alumina
JB20D50A	80% Diesel ,20% by vol.Jojoba ,50 mg/l	JBD25CNT	25 ppm CNT
Al2O3	Diesel ,50 ppm Alumina oxide	JBD50CNT	50 ppm CNT
CuO	Diesel ,50 ppm copper oxide	JBD25A25CNT	Alumina ,CNT (25ppm each)
B5	95% Diesel,5% Bio diesel	DAG10	10 ppm Silver powder
MWCNT	Multi walled carbon nano tube	DAG20	20 ppm Silver powder
E10	78.5% Diesel , 10 % Water, 11.5 % Glycerin	DAG40	40 ppm Silver powder
E15	75% Diesel, 15 % Water, 10 % Glycerin	A1	0.5wt% Al particle ,0.1wt% Span80
D3515	Diesel ,35 ppm Alumina,15 ppm Cobalt	B1	0.5wt% Boron particle ,0.1wt% Span80
D2525	Diesel ,25 ppm Alumina, 25 ppm Cobalt	F1	0.5wt% Iron particle ,0.1wt% Span80
D1535	Diesel ,15 ppm Alumina,35 ppm Cobalt		

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TABLE 2: CHEMICAL AND PHYSICAL PROPERTIES OF FUELS

Ref. No.	Fuel	Viscosity (cSt)	Flash point (°C)	Cal. value (MJ/kg)	Density@15°C (kg/m³)	Cetane No.
1	DIESEL	2.1	50	42.3	830	46
	D2S15W	4.9	62	38.8	858.5	43
	D2S15W25A	4.94	63	39.3	859.1	48
	D2S15W50A	4.98	65	39.8	859.3	50
	D2S15W100A	5.01	66	39.9	859.6	50
2	DIESEL	3	56	42	815	47
	MME	4.9	136	39.95	869	56
	MME20	3.4	76	41.62	826	49
	MME20+ANP50	3.37	71	41.665	827.5	49.5
	MME20+ANP100	3.33	65	41.69	829	51
3	DIESEL	2.61	-	44.7	825	57
	SOYBEAN DIESEL	4.78	-	41.2	865	49
	B20	3.7	-	43	847.7	42
	D80SBD15E4S1+ALUMINA	3.37	-	42.59	840	52
4	DIESEL	2.84	68	42.7	840	48
	JATROPA BIODIESEL	4.34	130	42.673	874.3	52.7
	ETHANOL	0.79	13.5	27	785	6
	BDE	2.86	20	39.982	840.2	53
	BDE+AL	2.57	22	39.137	837.2	54
5	DIESEL	2.54	50	-	833	52
	ZJME25	3.56	56	-	846	55
	AONP25	3.39	57	-	849	57
	AONP50	3.17	58	-	853	58
6	DIESEL	2.2	48	42.3	835	-
	JATROPA BIODIESEL	4.1	85	38.5	873	-
	JBD5A5C	4.25	80.5	38.8	876	-
	JBD15A15C	4.5	74.3	38.6	879	-
	JBD30A30C	4.8	70.2	38.2	883	-
7	B20	3.1	46	44.074	834	57
	D80B20ZNO50	3.1	47	44.334	833	58
	D80B20ZNO100	3.3	47	44.3	832	58
8	D	3.3	55	44.415	830	56.45
	P50	3.3	55.6	44.164	835	56.71
	P100	3.3	56.4	44.172	387	56.82
	N50	3.2	56.1	44.157	832	55.99
	N100	3.2	56.8	44.165	834	55.45
9	JBD	5.25	85	38.88	895	53
	JBD25A	5.31	84	39.22	896	54
	JBD50A	5.35	82	39.53	897	56
	JBD25CNT	5.29	83	39.5	895.5	55
	JBD50CNT	5.33	81	39.78	897.9	57
	JBD25A25CNT	5.36	81	39.99	895.2	57
10	JME	5.05	85	38.88	895	53
	JME2S5W	5.4	140	37.05	899.8	51
	JME2S5W25CNT	5.43	130	37.28	897.2	54
	JME2S5W50CNT	5.76	125	37.35	897.8	55
	JME2S5W100CNT	5.91	122	37.85	899.4	56

Carbon nano tube and Alumina when blended with Jatropha biodiesel by J. Brazet al.[9] shows nearly same density and calorific value when tested by standard ASTM procedures.

a) Effect on Cetane Number and Calorific Value:

Diesel's cetane number is a measure of the fuel's delay of ignition time i.e the amount of time between the injection of fuel into the combustion chamber and the actual start of combustion of the fuel charge. Marginal increase in Cetane index was observed with Aluminum nano particle in most of the investigation. Also slight improvement in calorific value of all the nano and emulsion blends was noted which denotes higher heat release during the combustion process.

III. Effect of nano fuel on Engine Performance:

a) Brake thermal Efficiency:

Mehta et al [14] prepared and stabilized nano emulsion fuels with water in diesel (W/D), nano aluminum in water-diesel (W/DA), nano silicon diesel (W/DS), which were tested with variable loads and significantly registered increase in brake thermal efficiency (BTE) as 16% and 14% for W/DA and W/DS respectively. Addition of nano particles enhanced calorific value promoting complete combustion due to higher evaporation rates, reducing ignition delay and hence promoting full release of thermal energy resulting into high thermal efficiency. Emulsion fuel with water concentration of 10% and 15% were prepared with organic material as Glycerin. Tested on four-cylinder diesel engine with constant speed resulted into higher BTE for E10 and E20 as compared to neat diesel. W.M.Yang et al.[19] also noted that E10 emulsion could give BTE as 7.8% increase and further of 14.2% increase in BTE at 1200 rpm and 3600 rpm respectively. E10 has better efficiency than E15 this is due to fact that E15 contains more water than E10 which bring down the flame temperature and affects the combustion process. M.A. Lenin et al. [15] prepared samples of diesel with manganese oxide and copper oxide by sol gel method, tested on a single cylinder resulted into 4% marginal increase in the BTE as compared to diesel. SadhikBasha et al [1]could find 28.9% BTE for D2S15W100A against 25.2% for neat diesel at full load condition. This is could be probably attributed to the presence of the potential alumina nano particle in water diesel emulsion fuel due to micro- explosion and secondary optimization phenomenon. T.Shaafi et al.[3] obtained an increase in thermal efficiency of 15.8% and 17.9% for B20 and D80SBD15E4S1 + alumina fuel blend respectively. This is due to the complete combustion that occurred in the B20, due to the presence of higher oxygen in the fuel and further increase in efficiency in case of D80SBD15E4S1 + alumina is due to micro explosion of primary droplet and higher evaporation rate due to presence of the alumina particle. C. Aalam [5] examined BTE on CRDI diesel engine and received maximum increase in BTE as 2.5% compared to neat diesel when 50 ppm dosing of Aluminum oxide was made to diesel. C. Aalam et al [2] obtained the BTE of the MME20 + ANP100 was better than that of other fuel blends and neat diesel a gain of 1.58% and 7.34% was recorded when ANP was added with MME20 in different concentration of 50 ppm and 100 ppm. Jatropha Methyl Ester (JME) nano emulsion received higher BTE in comparison to other blended fuel with JME tested by SadhikBasha et al [10]. Heat release rate is more in case of emulsion resulting into higher BTE. CNT blended fuel improves homogenization of fuel and air mixing causing combustion and burning characteristics showing 28.45% BTE for JME2E5W100CNT which is 24.80% for JME fuels. A. Prabhu et al [6] used mixture of Al_2O_3 and CeO_2nano particles which recorded 29%, 30% and 31% for JBD5A5C, JBD15A15C and JBD30A30C respectively

b) Brake Specific Fuel Consumption:

Brake Specific Fuel Consumption (BSFC) was observed as 0.32 kg/kWhr for D2S15W100A and for D2S15W50A, D2S15W25A, D2S15W is 0.33kg/kWhr, 0.33 kg/kWhr, 0.35 kg/kWhr and 0.33 kg/kWhr respectively. This result was obtained due to shortened ignition delay of nano fuels[1]. Whereas decrease in up to 0.5% with CuO additives and decrease by upto 1.2% with Al_2O_3 was noted by C. Aalam et al [2] this result could be possible due to abandoned Oxygen and effect of nano particle on physical properties of diesel fuel causes to increase in combustion efficiency which in turn showed reduced BSFC. Diesel Soyabean bio-diesel(B20) when tested against added Alumina particle at variable loads found BSFC to be lowest for 25% ans 50% of load. Due to lower calorific value of these fuel a drop of 10.50% and 11.46% was recorded for full load[3]. H Venu et al[4] tested effect of Al_2O_3 with retarded and advanced injection timing on BSFC. Retarded injection timing resulted into 9.37% reduction in BSFC at part load condition. AT original injection loads BSFC reduced by 12%, 1%, 9.37% and 12.5% for engine loads of 25%, 50%, 75% and 100%. When nano additives dispersed in BDE at advanced injection timing BSFC were higher by 4.65%, 6.99%, 19.35% and 4% for 25%, 50%, 75% and 100% engine loads respectively. Aluminum oxide particle, oxidized the carbon deposits in the engine cylinder leading to reduced fuel consumption, thus BSFC of AONP blended is lower than that of ZJME25 for all loads[5]. for JBD15A15C, JBD30A30C increased BSFC was found as 0314kg/kWh, 0.303kg/kWh, 0.293kg/kWh respectively[7]. A. Kenskin et al[8] made comparison of BSFC of diesel with P50, P100, N50 and N100 blendes and found 1.29%, 3.28%, 1.72% and 3.1% decrease in BSFC respectively. Maximum was obtained with P100 at 1600 rpm as 7.75%. JME2S5W100CNT fuels showed BSFC as 0.301kg/kWhr as compared to JME2SW25CNT, JME2S5W50CNT which was 0.315 kg/kWhr , 0.308 kg/kWhr respectively[10]. H.SaukhtSaraee et al[11] recorded increase of fuel consumption by 40 ppm of silver nano particle added to bio diesel. Maximum reduction rate of 3% was observed for D10 fuel maximum increase rate of 4.3% and 1% were associated with D40 fuel at 1900rpm and D40 at 1800 rpm respectively. Boron and Aluminum nano particles showed increase in fuel consumption as compared to diesel at lower load due to preheating and ignition stages whereas ferrous showed

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TABLE 3: PERFORMANCE CHARACTERISTICS

Ref. No	Engine Type	Test condition	Fuels	Nano Additives	Performance		
					Power	BSFC	BTE
1	4S, 1-cylinder, AC, CR 17.5:1	Constant Speed (1500 RPM)	Diesel	-	-	0.33 Kg/KWh	25.2%
			D2S15W	Diesel(83%)+Surfactant(2%)+Water(15%)	-	0.35Kg/KWh	26.9%
			D2S15W25A	Diesel(83%)+Surfactant(2%)+Water(15%)+Alumina(25 ppm)	-	0.33 Kg/KWh	27.9%
			D2S15W50A	Diesel(83%)+Surfactant(2%)+Water(15%)+Alumina(50 ppm)	-	0.33 Kg/KWh	28.3%
			D2S15W100A	Diesel(83%)+Surfactant(2%)+Water(15%)+Alumina(100 ppm)	-	0.32 Kg/KWh	28.9%
2	4S, Vertical, water cooled, CR 17.5:1	Constant Speed (1500 RPM)	Diesel	-	-	0.3 kg/kWh	25%
			MME20	Mahua Methyl Ester(20%) + Diesel(80%)	-	0.32 kg/kWh	25%
			MME20+ANP50	Mahua Methyl Ester(20%) + Diesel(80%)+ Alumina(50 ppm)	-	0.33kg/kWh	26%
			MME20+ANP100	Mahua Methyl Ester(20%) + Diesel(80%) + Alumina (100 ppm)	-	0.33kg/kWh	27%
3	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	variable speed	Diesel	-	-	0.349kg/kWh	
			Diesel + Soybean oil(B20)	80% diesel, 20% Soybean	-	↓10.60%	↑ 15.8%
			Diesel + Soybean+ ethanol+isopropanol (D80SBD15E4S1 + alumina)	80%diesel, 15%soybean,4%ethanol,1%isopropanol, Alumina 100mg/L	-	↓11.46% (0.309kg/kWh)	↑17.9%
6	1-cylinder, RP: 4.4kW at 1500 RPM, CR:17.5:1, AC	Constant Speed (1500 RPM)	Diesel	-	-	0.263 kg/kWh	0.32.33
			Bio diesel	Jatropha oil	-	0.318 kg/kWh	0.286
			Diesel+Jatropha+Alumina+Cerium	Alumina 5 ppm and Cerium 5 ppm	-	0.314kg/kWh	0.29
			Diesel+Jatropha+Alumina+Cerium	Alumina 15 ppm and Cerium 15 ppm	-	0.303kg/kWh	0.3
			Diesel+Jatropha+Alumina+Cerium	Alumina 30 ppm and Cerium 30 ppm	-	0.293kg/kWh	0.31

Ref.	Engine Type	Test condition	Fuels	Nano Additives	Power	BSFC	BTE
7	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	variable speed	Diesel + Pomolin Stearin Wax Methyl Ester(B20)	80% Diesel + 20% PSWME	-	0.284kg/kWh	0.28
			Diesel + Pomolin Stearin Wax Methyl Ester+Zinc	80% Diesel + 20% PSWME + 50 ppm Zic Oxide	-	0.278 kg/kWh	0.288
			Diesel + Pomolin Stearin Wax Methyl Ester+Zinc	80% Diesel + 20% PSWME + 100 ppm Zic Oxide	-	0.272 kg/kWh	0.2996
8	1-cylinder, 13HP, CR:17:1, AC	Constant Speed	Diesel	-	11.8 kW (3000 RPM)	-	-
			Diesel + Palladium (P50)	PdL_2 50 ppm	11.57kW (3000 RPM)	↓1.29%	-
			Diesel + Palladium (P100)	PdL_2 100 ppm	11.78kW (3000 RPM)	↓3.28%[Max7.75% at 1600RPM]	-
			Diesel + Nickel (N50)	NiL_2 50 ppm	11.51kW (3000 RPM)	↓1.72%	-
			Diesel + Nickel (N100)	NiL_2 100 ppm	11.72kW (3000 RPM)	↓3.1%	-
9	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Constant Speed	Jatropha biodiesel (JBD)	-	-	0.37kg/kWh	24.9%
			Jatropha + Alumina (JBD25A)	25 ppm alumina	-	-	-
			Jatropha+ Alumina (JBD50A)	50 ppm alumina	-	0.32kg/kWh	27.9%
			jatropha +CNT(JBD25CNT)	25 ppm CNT	-	-	..
			jatropha + CNT(JBD50CNT)	50 ppm CNT	-	0.33kg/kWh	27.1%
			Jatropha + Alumina+CNT(JBD25A25CNT)	Alumina + CNT (25ppm each)	-	0.31kg/KWh	28.9%
11	6-cylinder, RP:82kW, CR:16:1, AC	variable speed	Diesel + Silver Nano powder(DAG10)	10 ppm Silver powder	Approx. 4% in every combination Maximum for DAG 40 of 64.2kW at 1710RPM	↓ 3%	-
			Diesel + Silver Nano powder(DAG20)	20 ppm Silver powder		↑ 4.3% at 1900RPM	-
			Diesel + Silver Nano powder(DAG40)	40 ppm Silver powder		↑ 1 % at 1805RPM	-
12	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Constant Speed (1500 RPM)	Diesel + Aluminum+ Span80(A1)	0.5wt% Al particle + 0.1wt% Span80	-	↓7%	↑9%
			Diesel +boron+ Span80(B1)	0.5wt% Boron particle + 0.1wt% Span80	-	marginal increase	↑2%
			Diesel + iron+ Span80(F1)	0.5wt% Iron particle + 0.1wt% Span80	-	marginal increase	↑4%

Ref. No	Engine Type	Test condition	Fuels	Nano Additives	Power	BSFC	BTE
13	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Constant Speed (1500 RPM)	Diesel (D0000)	-	-	0.6kg/kWh	28%
			Diesel + Alumina+ Cobalt (D3515)	Diesel +35 ppm Alumina+ 15 ppm Cobalt	-	0.55kg/kWh	27%
			Diesel + Alumina+ Cobalt (D2525)	Diesel +25 ppm Alumina+ 25 ppm Cobalt	-	0.53kg/kWh	29%
			Diesel + Alumina+ Cobalt (D1535)	Diesel +15 ppm Alumina+ 35 ppm Cobalt	-	0.52kg/kWh	26%
14	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	variable speed	Diesel	-	-	-	-
			water in diesel (W/D)	1% vol water	-	marginally high	-
			Nano -aluminum in water and diesel (W/DA)	1%vol.water + 0.1%wt nAl	-	↓21%	↑16%
			Nano -silicon in water and diesel(W/DS)	1%vol.water + 0.1%wt nSi	-	↓37%	↑14%
15	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Constant Speed	Diesel	-	-	-	27%
			Diesel + manganese oxide(MnO)	200 mg of MnO in 1L of diesel	-	-	25%
			Diesel + copper oxide(CuO)	200 mg of MnO in 1L of diesel	-	-	24%
16	4s, 1-cylinder, 55kW,	Two speeds	Diesel (D100)	-	-	370g/kW.h (1500RPM) 380g/kWh (1300RPM)	23%(1500RPM) 23%(1300RPM)
			Jojoba Bio diesel (JB20D)	80% Diesel + 20% by vol.Jojoba	-	390 g/kWh (1500RPM) 405 g/kWh (1300RPM)	20%(1500RPM) 20%(1300RPM)
			Jojoba +Alumina (JB20D10A)	80% Diesel + 20% by vol.Jojoba + 10 mg/l	-	365 g/kWh (1500RPM) 410 g/kWh (1300RPM)	21%(1300RPM) 20%(1500RPM)
			Jojoba +Alumina (JB20D20A)	80% Diesel + 20% by vol.Jojoba + 20 mg/l	-	380 g/kWh (1500RPM) 400 g/kWh (1300RPM)	21%(1500RPM) 21%(1300RPM)
			Jojoba +Alumina (JB20D30A)	80% Diesel + 20% by vol.Jojoba + 30 mg/l	-	382 g/kWh (1500RPM) 355 g/kWh (1300RPM)	21%(1500RPM) 21%(1300RPM)
			Jojoba +Alumina (JB20D40A)	80% Diesel + 20% by vol.Jojoba + 40 mg/l	-	355 g/kWh .h(1500RPM) 360 g/kWh 1300RPM)	24%(1500RPM) 24%(1300RPM)
			Jojoba +Alumina (JB20D50A)	80% Diesel + 20% by vol.Jojoba + 50 mg/l	-	385 g/kWh (1500RPM) 355g/kWh (1300RPM)	22%(1500RPM) 22%(1300RPM)
17	4s, 1-cylinder, 5.1kW, CR 20.3:1	variable speed	Diesel	-	5.2KW	273 g/kwh	-
			Diesel + Alumina oxide(Al2O3)	Diesel + 50 ppm Alumina oxide	5.5KW	270 g/kwh	-
			Diesel + copper oxide(CuO)	Diesel + 50 ppm copper oxide	5.2KW	272 g/kwh	-

Ref. No	Engine Type	Test condition	Fuels	Nano Additives	Power	BSFC	BTE
18	4S, 6-cylinder, CR 16.1:1	constant speed	Diesel+ Bio diesel (B5)	95% Diesel+ 5% Bio diesel	-	-	-
			Diesel+ Bio diesel (B20)	80% Diesel+ 20% Bio diesel	-	-	-
			Diesel+ Bio diesel +MWCNT-	B5 + 30 ppm MWCNT-amide catalyst	↑0.58%	↓0.42%	-
			Diesel+ Bio diesel +MWCNT-	B5 + 60 ppm MWCNT-amide catalyst	↑1.79%	↓0.84%	-
			Diesel+ Bio diesel +MWCNT-	B5 + 90 ppm MWCNT-amide catalyst	↑3.25%	↓3.09%	-
			Diesel+ Bio diesel +MWCNT-	B20 + 30 ppm MWCNT-amide catalyst	↑2.28%	↓0.34%	-
			Diesel+ Bio diesel +MWCNT-	B20 + 60 ppm MWCNT-amide catalyst	↑5.72%	↓1.49%	-
			Diesel+ Bio diesel +MWCNT-	B20 + 90 ppm MWCNT-amide catalyst	↑7.81%	↓4.51%	-
19	4s, 4-cylinder, 75kW, CR:18.	variable speed	Diesel	-	-	-	32%
			Diesel + water + Glycerin (E10)	78.5% Diesel + 10 % Water + 11.5 % Glycerin	-	-	33%
			Diesel + water + Glycerin (E15)	75% Diesel + 15 % Water + 10 % Glycerin	-	-	37%

↓ - increase; ↓ decrease

IV. Effect of nano fuel on emission characteristics

1. Effect on NOx emission:

Emission of NOx mainly depends on temperature, the local concentration of oxygen and duration of combustion during different combustion phases on the different combustion zones. Addition of nano particles increases the diffusion controlled combustion duration which helps in increase of NOx[5]. NOx emission decreased for water-diesel emulsion as compared to neat diesel and even further reduced by help of nano particles. It is observed that D2S15W100A has 891 ppm NOx as compared to 1340 ppm of neat diesel [1].This may be due to fact that lower the exhaust gas temperature because of more water concentration[19]. At part load NOx emission was found to be same for B20 and D80SBD5E4S1+Alumina. Surprisingly B20 resulted more emission in comparison to D80SBD5E4S1+Alumina at 50% load. At full load increase in emission was 7.2% and 9.9% was noted for B20 and D80SBD5E4S1+Alumina[3]. Addition of Silver nano particle also have reduced the value of 20-23% in idle mode of 1900 rpm for D40. Maximum NOx of 1427 ppm is related to diesel at 1330 rpm. For 20 ppm nano particle blend at 1900 rpm was found with 250 ppm of NOx[11]. H. Venu et al [3] when performed testing with Injection Timing (IT) RET IT slips on to NOx by 25.89% , 22.86%, 15.98%, 8.55% and 1.31% at engine load of 0%, 25%, 75% and 100% respectively. Also Al_2O_3 reduced NOx by 9.11% and 5.92% at 50% and 75% at 50% and 75% load. On the other hand NOx was increased by 5.44% and 5.13% for 75% and 100% load when operated with ADV IT. According to Zeldovich thermal mechanism an increase of 5% and 3% of NOx was recorded for A_1 and F_1 particles as compared to diesel and B_1nanofuels[12]. Emulsion of water diesel (W/D) showed reduction of 13% in comparison to diesel on the contrary W/DA and W/DS increased NOx emission by 5% and 4% respectively [14].

2. Effect on Hydrocarbon (HC) emission:

Oxygen content is main reason for HC emission reduction and complete combustion. Increase of AONP dosing level with ZJME bio diesel resulted in increase of 0.2169 /kWhr, 0.6129/kWhr and 0.318/kWhr for ZJME25, AONP25 and AONP50 blends respectively [5]. W.M.Yang et al[19] found HC emission to be increased for lower loads for E10 and E15 fuels. Fuel air equivalence ratio of the diesel engine is low and there is enough oxygen available for fuel to burn completely and thus HC emissions are very low for E10, E15 and diesel. With MME20+ANP100 fuel reduction of HC was noted as 26.04% at full load as ANP supplies the oxygen for the oxidation of hydrocarbon [2]. Metal oxide nano particles acts as oxygen donating catalyst which provides oxygen for oxidation. HC reduced by 13% and 5% when Al_2O_3 and CuO blends were used[17].

3. Effect on Carbon monoxide (CO) emission:

Characteristic of shortened ignition delay enhances combustion process in turn the degree of fuel air-mixture and uniform burning is possible, thus appreciable reduction in Carbon monoxide is observed for Alumina oxide [5]. Increase in CO emission was noticed by 66% at 25% load for D80SBD15E4S1+Alumina and it was reduced by 40% at full load in comparison to B20 and neat diesel. This was possible might be due to the fuel-rich operating condition at low load in presence of nano particles and also due to fuel-lean combustion the nano particle enhances the atomization rate at full load [6]. 68.15% decrease in CO recorded with metal particles of Palladium (II) and Nickel (NiL_2)[8]. Jatropha Methyl Ester blended with water shows 0.085% (by Vol.) CO emission and same goes to reduce at 0.06% (by Vol.) when blended with carbon nano tube by 100 ppm. This is also explained by poor air fuel mixing of water emulsion and nano particle accelerates combustion process.

V. Conclusion

Nano metal particles are used to blend with diesel and biodiesel in scope of improving overall efficiency of CI engine. Analysis shows following conclusion

1. Nano particle improves the cetane number and density. Increase in calorific value and flash point was remarkable.
2. With Alumina nano particle brake thermal efficiency has increased approx. 2% to 4% with any of diesel or biodiesel blends.
3. Marginal decrease of 1% to 3% in BSFCshown by papers. However in emulsion blends increase in brake fuel consumption is also noticed.
4. Better combustion in nano fuel showed reduction in HCin all metal blends examined at full load condition whereas showed increase when Jajoba bio diesel is blended with Alumina
5. With almost all metal particle reduction in NOx is possible but significant reduction was upto 2% -4% when used alumina nano particles.
6. CO also reduced while using nano fuel due to shortened ignition delay.

ABLE 4: EMISSION CHARACTERISTICS

Ref. No.	Engine Type	Test condition	Fuels	Nano Additives	Emission				
					NOx	CO	UHC	Smoke Opacity	CO2
1	4S, 1-cylinder, AC, CR 17.5:1	Constant Speed (1500 RPM)	Diesel	-	1340 ppm		82 ppm	71%	-
			D2S15W	Diesel(83%)+Surfactant(2%)+Water(15%)	1009 ppm	0.4%	91 ppm	50%	-
			D2S15W25A	Diesel(83%)+Surfactant(2%)+Water(15%)+Alumina (25 ppm)	989 ppm	0.5%	80 ppm	49%	--
			D2S15W50A	Diesel(83%)+Surfactant(2%)+Water(15%)+Alumina (50 ppm)	945 ppm	0.42%	74 ppm	48%	-
			D2S15W100A	Diesel(83%)+Surfactant(2%)+Water (15%)+Alumina(100 ppm)	891 ppm	0.4%	71 ppm	45%	-
2	4S, Vertical, water cooled, CR 17.5:1	Constant Speed (1500 RPM)	Diesel	-	880 ppm	0.50%	95 ppm	68 HSU	
			MME20	Mehua Methyl Ester(20%) + Diesel(80%)	890 ppm	0.48%	90 ppm	65 HSU	
			MME20+ANP50	Mehua Methyl Ester(20%) + Diesel(80%)+ Alumina (50 ppm)	900 ppm	0.35%	78 ppm	55 HSU	
			MME20+ANP100	Mehua Methyl Ester(20%) + Diesel(80%) + Alumina (100 ppm)	950 ppm	0.25%	70 ppm	48 HSU	
3	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Variable Speed	Diesel	-	1792 ppm	0.05%	37.5 ppm	-	
			Diesel + Soybean oil(B20)	80% diesel, 20% Soybean	1921 ppm(↑7.2%)	0.05%	48 ppm	-	↑2.2 %
			Diesel + Soybean+ ethanol+isopropanol (D80SBD15E4S1 + alumina)	80%diesel, 15%soybean,4%ethanol,1%isopropanol, Alumina 100mg/L	1971 ppm(↑9.2%)	0.028 %	46 ppm	-	↓3.3 %

Ref. No.	Engine Type	Test condition	Fuels	Nano Additives	NOx	CO	UHC	Smoke Opacity	CO2
6	1-cylinder, RP: 4.4kW at 1500 RPM, CR:17.5:1, AC	Constant Speed (1500 RPM)	Diesel	-	1320 ppm	0.09%	25 ppm	43.50%	
			Bio diesel	Jatropha oil	1390 ppm	0.05%	18 ppm	37.60%	
			Diesel+Jatropha+Alumina+Cerium oxide(JBD5A5C)	Alumina 5 ppm and Cerium 5 ppm	1302 ppm	0.03%	17 ppm	33.40%	
			Diesel+Jatropha+Alumina+Cerium oxide(JBD15A15C)	Alumina 15 ppm and Cerium 15 ppm	1249 ppm	0.03%	15 ppm	30.20%	
			Diesel+Jatropha+Alumina+Cerium oxide(JBD30A30C)	Alumina 30 ppm and Cerium 30 ppm	1208 ppm	0.02%	12 ppm	25.60%	
7	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Variable Speed	-	-	at higher load for all the blend NOx remains the same	24 ppm	33.5 ppm	9%	
			Diesel + Pomolin Stearin Wax Methyl Ester+Zinc Oxide(D80B20ZnO50)	80% Diesel + 20% PSWME + 50 ppm Zinc Oxide		22 ppm	32.5 ppm	8.70%	
			Diesel + Pomolin Stearin Wax Methyl Ester+Zinc Oxide(D80B20ZnO100)	80% Diesel + 20% PSWME + 100 ppm Zinc Oxide		21 ppm	31.5 ppm	8%	
8	1-cylinder, 13HP, CR:17:1, AC	Constant Speed	Diesel	-	-	-	-	-	-
			Diesel + Palladuim (P50)	PdL_2 50 ppm	↓4.17%	↓32.65%	-	↓29.01%	-
			Diesel + Palladuim (P100)	PdL_2 100 ppm	↓7.43%	↓42.56%	-	↓37.63%	-
			Diesel + Nickel (N50)	NiL_2 50 ppm	↓16.04%	↓44.53%	-	↓31.6%	-
			Diesel + Nickel (N100)	NiL_2 100 ppm	↓20.07%	↓50.24%	-	↓39.64%	-
9	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Constant Speed	Jatropha biodiesel (JBD)	-	1282 ppm	-	60 ppm	67%	-
			Jatropha + Alumina (JBD25A)	25 ppm alumina	-	-	-	-	-
			Jatropha+ Alumina (JBD50A)	50 ppm alumina	1015 ppm	-	52 ppm	58%	-
			jatropha +CNT(JBD25CNT)	25 ppm CNT	-	-	-	-	-
			jatropha + CNT(JBD50CNT)	50 ppm CNT	1001 ppm	-	49 ppm	60%	-
			Jatropha+ Alumina+CNT(JBD25A25CNT)	Alumina + CNT (25ppm each)	985 ppm	-	46 ppm	57%	-

Ref. No.	Engine Type	Test condition	Fuels	Nano Additives	NOx	CO	UHC	Smoke Opacity	CO_2
11	6-cylinder, RP:82kW, CR:16:1, AC	Variable Speed	Diesel + Silver Nano powder(DAG10)	10 ppm Silver powder	220 ppm	0.10%	12 ppm	-	-
			Diesel + Silver Nano powder(DAG20)	20 ppm Silver powder	240 ppm	0.30%	10 ppm	-	-
			Diesel + Silver Nano powder(DAG40)	40 ppm Silver powder	230 ppm	0.30%	10 ppm	-	-
12	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Constant Speed (1500 RPM)	Diesel + aluminuim+ Span80(A1)	0.5wt% Al particle + 0.1wt% Span80	3.8 %	0.01%	21 ppm	-	-
			Diesel +boron+ Span80(B1)	0.5wt% Boron particle + 0.1wt% Span80	3.6 %	0.02%	22 ppm	-	-
			Diesel + iron+ Span80(F1)	0.5wt% Iron particle + 0.1wt% Span80	3.2 %	0.015%	23 ppm	-	-
13	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Constant Speed (1500 RPM)	Diesel (D0000)	-	1300 ppm	0.05%	54 ppm	37%	-
			Diesel + Alumina+ Cobalt (D3515)	Diesel +35 ppm Alumina+ 15 ppm Cobalt	1250 ppm	0.09%	58 ppm	42%	
			Diesel + Alumina+ Cobalt (D2525)	Diesel +25 ppm Alumina+ 25 ppm Cobalt	1320 ppm	0.10%	56 ppm	50%	
			Diesel + Alumina+ Cobalt (D1535)	Diesel +15 ppm Alumina+ 35 ppm Cobalt	1200 ppm	0.04%	43 ppm	15%	
14	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	variable speed	Diesel	-	-	-	-	-	-
			water in diesel (W/D)	1% vol water	↓ 13%	0.051%	decreased at lower loads and increased at higher loads	-	-
			nano -aluminium in water and diesel (W/DA)	1%vol.water + 0.1%wtnAl	↑5%	0.050%	↑9%	-	-
			nano -silicon in water and diesel(W/DS)	1%vol.water + 0.1%wtnSi	↑4%	0.048%	↑4%	-	-

Ref. No.	Engine Type	Test condition	Fuels	Nano Additives	NOx	CO	UHC	Smoke Opacity	CO_2
15	4S, 1-cylinder, 4.4kW CR: 17.5:1,AC	Constant Speed	Diesel	-	7.40%	0.01%	0.50%	-	-
			Diesel + manganese oxide(MnO)	200 mg of MnO in 1L of diesel	7.18%	0.007%	0.50%	-	-
			Diesel + copper oxide(CuO)	200 mg of MnO in 1L of diesel	7.20%	0.005%	0.50%	-	-
16	4s, 1-cylinder, 55kW,	Two speeds	Diesel (D100)	-	650ppm (1500RPM) 640ppm (1300RPM)	0.13%vol (1500RPM) 0.09%vol (1300RPM)	11ppm (1500RPM) 10ppm (1300RPM)	72% (1500RPM) 78% (1300RPM)	-
			Jojoba Bio diesel (JB20D)	80% Diesel + 20% by vol.Jojoba	700ppm (1500RPM) 600ppm (1300RPM)	0.18%vol (1500RPM) 0.17%vol (1300RPM)	13ppm (1500RPM) 11.8ppm (1300RPM)	80% (1500RPM) 85% (1300RPM)	-
			Jojoba +Alumina (JB20D10A)	80% Diesel + 20% by vol.Jojoba + 10 mg/l	180ppm (1500RPM) 210ppm (1300RPM)	0.04%vol (1500RPM) 0.03%vol (1300RPM)	6.5ppm (1500RPM) 6ppm (1300RPM)	80% (1500RPM) 78% (1300RPM)	-
			Jojoba +Alumina (JB20D20A)	80% Diesel + 20% by vol.Jojoba + 20 mg/l	160ppm (1500RPM) 190ppm (1300RPM)	0.06%vol (1500RPM) 0.03%vol (1300RPM)	6.5ppm (1500RPM) 6ppm (1300RPM)	72% (1500RPM) 78% (1300RPM)	-
			Jojoba +Alumina (JB20D30A)	80% Diesel + 20% by vol.Jojoba + 30 mg/l	175ppm (1500RPM) 180ppm (1300RPM)	0.04%vol (1500RPM) 0.03%vol (1300RPM)	4.5ppm (1500RPM) 5ppm (1300RPM)	86% (1500RPM) 82% (1300RPM)	-
			Jojoba +Alumina (JB20D40A)	80% Diesel + 20% by vol.Jojoba + 40 mg/l	210ppm (1500RPM) 250ppm (1300RPM)	0.06%vol (1500RPM) 0.04%vol (1300RPM)	5.8ppm (1500RPM) 6ppm (1300RPM)	88% (1500RPM) 80% (1300RPM)	-
			Jojoba +Alumina (JB20D50A)	80% Diesel + 20% by vol.Jojoba + 50 mg/l	170ppm (1500RPM) 200ppm (1300RPM)	0.03%vol (1500RPM) 0.02%vol (1300RPM)	6.5ppm (1500RPM) 6ppm (1300RPM)	78% (1500RPM) 78% (1300RPM)	-

Ref. No.	Engine Type	Test condition	Fuels	Nano Additives	NOx	CO	UHC	Smoke Opacity	CO_2
17	4s, 1-cylinder, 5.1kW, CR 20.3:1	variable speed	Diesel	-	1310 ppm	90 ppm	2.30%	-	-
			Diesel + Alumina oxide(Al2O3)	Diesel + 50 ppm Alumina oxide	1280 ppm	89 ppm	2.20%	-	-
			Diesel + copper oxide(CuO)	Diesel + 50 ppm copper oxide	1250 ppm	85 ppm	2.20%	-	-
18	4S,6-cylinder, CR 16.1:1	constant speed	Diesel+ Bio diesel (B5)	95% Diesel+ 5% Bio diesel	5.14 g/kWh	6.72 g/kWh	0.13 g/kWh	-	-
			Diesel+ Bio diesel (B20)	80% Diesel+ 20% Bio diesel	5.25 g/kWh	6.78 g/kWh	0.14 g/kWh	-	-
			Diesel+ Bio diesel +MWCNT-amide(B5)(30ppm)	B5 + 30 ppm MWCNT-amide catalyst	4.85 g/kWh	6.68 g/kWh	0.13 g/kWh	-	-
			Diesel+ Bio diesel +MWCNT-amide(B5)(60ppm)	B5 + 60 ppm MWCNT-amide catalyst	4.81 g/kWh	5.99 g/kWh	0.08 g/kWh	-	-
			Diesel+ Bio diesel +MWCNT-amide(B5)(90ppm)	B5 + 90 ppm MWCNT-amide catalyst	4.19 g/kWh	4.58 g/kWh	0.06 g/kWh	-	-
			Diesel+ Bio diesel +MWCNT-amide(B20)(30ppm)	B20 + 30 ppm MWCNT-amide catalyst	5.22 g/kWh	5.74 g/kWh	0.13 g/kWh	-	-
			Diesel+ Bio diesel +MWCNT-amide(B20)(30ppm)	B20 + 60 ppm MWCNT-amide catalyst	4.70 g/kWh	5.42 g/kWh	0.06 g/kWh	-	-
			Diesel+ Bio diesel +MWCNT-amide(B20)(30ppm)	B20 + 90 ppm MWCNT-amide catalyst	4.26 g/kWh	4.15 g/kWh	0.04 g/kWh	-	-
19	4s, 4-cylinder, 75kW, CR:18.5:1,	variable speed	Diesel	-	780 ppm	9 ppm	6 ppm	-	-
			Diesel + water + Glycerin (E10)	78.5% Diesel + 10 % Water + 11.5 % Glycerin	700 ppm	8 ppm	7 ppm	-	-
			Diesel + water + Glycerin (E15)	75% Diesel + 15 % Water + 10 % Glycerin	660 ppm	8 ppm	4 ppm	-	-

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