THEORETICAL AND EXPERIMENTAL VALIDATION OF PERFORMANCE AND EMISSION CHARACTERISTICS OF NANOADDITIVE BLENDED DIESEL ENGINE

K.Ramesh Babu [1*], R.Bharathi Raja [2]

1 - Associate Professor, SVS College of Engineering - Coimbatore-09, Email: rabakrishnan@gmail.com*

2 - Assistant Professor, Mechanical Engineering, SVS College of Engineering-Coimbatore-09 Email: rbraja23@gmail.com

Abstract

Worldwide energy demand has been growing steadily during the past five decades and experts believe that this trend will continue to rise. An experimental investigation is carried out to establish the performance, emission and combustion characteristics of a diesel engine using diesel fuel and alumina-nanoparticle blended diesel fuel. The nanoparticles of alumina are mixed with the diesel fuel in the mass fractions of 25 ppm to 75 ppm systematically. The investigation is carried out using an experimental set-up consisting of a single-cylinder diesel engine coupled with an eddy current loading device, an AVL DiGas 4000 Light analyzer, an AVL smoke meter, and a data-acquisition system. Theoretical Investigation was carried out by creating a 2D IC Engine model using the ICEM CFD software and solved using the Fluent Software. The blending of nanoparticle reduces viscosity, shortens the ignition delay and increase the atomization which in turn will reduce NOx and increase the efficiency. The experimental results were compared with that of simulated values and a reasonable agreement between them was noticed.

Keywords: Diesel Engine; CFD; Nano; AVL.

1. Introduction

The compression ignition engines are widely used due to its reliable operation and economy. As the petroleum reserves are depleting at a faster rate due to the growth of population and the subsequent energy utilization, an urgent need for search for a renewable alternative fuel arise. Also the threat of global warming and the stringent government regulation made the engine manufacturers and the consumers to follow the emission norms to save the environment from pollution. It is necessary to improve the combustion process to reduce exhaust emissions.

Among the various techniques available to reduce exhaust emissions, the use of fuel-borne catalyst is currently focused due to the advantage of increase in fuel efficiency while reducing harmful greenhouse gas emissions and the health-threatening chemicals such as NOx and particulate matter. The influence of aluminum oxide additive on ultrafine diesel particle emissions and kinetics of oxidation are studied.

Computational Fluid Dynamics is popularly used in different stages of engine design and optimization. Combustion research is more extensive, diverse and interdisciplinary due to powerful modelling tool like CFD. The challenge in using CFD is the complexity of interaction of flow, turbulence, spray and combustion inside the IC engine cylinder. High pressure Injection and modification of combustion chamber geometry were tried to reduce particulate emissions.

In the present work, the stable diesel fuel blends are prepared and the emission reduction potential are investigated using alumina (aluminum oxide) nanoparticles as fuel borne additive with neat diesel on the compression ignition engine. The CFD simulation of a diesel engine combustion process to predict the temperature distribution inside the cylinder and NOx emission with different properties of the pure and blended diesel fuel with Nano alumina. A 2D IC Engine model is created using the ANSA CFD software and solved using the Fluent Software for different propositions of Nano alumina in 25ppm to 75ppm with diesel fuel. The observations of the experimental analysis have been presented.

2. ENGINE PARAMETERS:

- TABLE I
- ENGINE SPECIFICATIONS

Type	Single Cylinder, Vertical, Four Stroke Cycles, Water Cooled Diesel Engine
Bore (mm)	87.5
Stroke (mm)	110
Displacement (cm3)	379
Compression ratio	17.5:1
RPM	1800
HP	7.5
Fuel nozzle injection pressure(bar)	180

3. METHODOLOGY:

1. Experimental Setup and Procedure

The experimental investigations were carried out in two phases. In the first phase, the various physicochemical properties of modified diesel were determined and compared with those of the base fuels. The properties flash, fire points, and viscosity. Standard ASTM test procedures were used in the experiments. In the second phase, extensive performance tests were conducted on a single cylinder compression ignition engine using the modified and base fuels, in order to evaluate the engine performance as well as the emission characteristics using an exhaust gas emission analyzer.

A) Preparation of Modified Fuels (Ultrasonification)

The fuel used for the current investigation is diesel. The viscosity, density, and Calorific value of the diesel are 3.2 cSt at 40°C, 883 kg/m^3 and 42.5 MJ/Kg, respectively. The fuel additive used is Aluminum oxide, in the form of commercially available nanoparticles of size > 50 nanometers and density of 3.97 g/mL. The dosing level of the Aluminum oxide nanoparticle samples (by weight) in the base fuel was varied from 25 to 75 ppm. The required quantity of the nanoparticle sample required for each dosing level was measured using a precision electronic balance and mixed with the fuel by means of an Ultrasonicator (**UP 400S – ULTRASONIC PROCESSOR)** , applying a constant agitation time of 30 minutes to produce a uniform suspension in 2L beaker. Normally Ultrasonification carried out ordinarily with liquid but in this case we are using diesel fuel. Since the beaker gets heated during the process, ice bath was used to cool the beaker. The modified fuel should be used within 8 days, in order to avoid any settling or for sedimentation to occur.

TABLE II.
SPECIFICATION OF ULTRASONICATOR

Rated Voltage	200-400 V
Rated Current	4A
Rated Frequency	50/60 Hz
Amplitude	20% to 100 %

B) Determination of Fuel Properties.

The viscosity, flash and fire points were measured using standard test methods. The viscosity was measured using the Redwood viscometer. A Cleveland open cup flash and fire point apparatus was used for measuring the flash point, and fire point.

Fig .1 Photographic View of Ultrasonicator during Fuel Preparation

C) Instrumentation System

The instrumentation system consists of AVL DiGas 4000 Light analyzer, AVL 437Smokemeter (0-100%), data-acquisition system comprising Kistler piezoelectric pressure transducer and a crank-angle encoder. The DiGas 4000 Light analyzer is used to measure the exhaust emissions such as NO*x*, CO, Unburnt HC and CO2, and the smoke opacity of the exhaust gases is measured by the Smoke meter.

TABLE III.
SPECIFICATIONS OF EXHAUST GAS ANALYZER

Measuring item	**Measuring method**	**Measuring range (vol)**	**Resolution (vol)**
CO	NDIR (Non Dispersive Infra Red)	0 -10 %	0.01%
HC	NDIR	0 - 20,000 ppm	1 ppm
CO_2	NDIR	0-20 %	0.1%
O_2	Electrochemical	0-25 %	0.01%
NOx	Electrochemical	0-5000 ppm	1 ppm

D) Test Procedure

All the tests are conducted by starting and warming up the engine with neat diesel and then switching to modified fuel (nanoparticles-blended diesel fuels). At the end of the test, the engine is made to run with neat diesel to blush out the nanoparticles-blended diesel fuels from the fuel line systems. The experiments are conducted for the tested fuels at a speed range of 1500 – 1900 rpm by varying the loads at a constant injection timing of 26° bTDC.

2. Model Generation and Post processing

A) **Solid Model Generation using Gambit software.**

The analysis has to be started by creating the geometry of the model. There is lot of options through which the geometry of the model is created. This generally involves modeling the geometry with a design software package and approximations of the geometry and simplifications may be required to allow an FLUENT with reasonable effort. In this case the cross section of IC engine is designed 2 dimensionally using ANSA software. The geometry and flow domain are modeled in such a manner as to provide input for the grid generation.

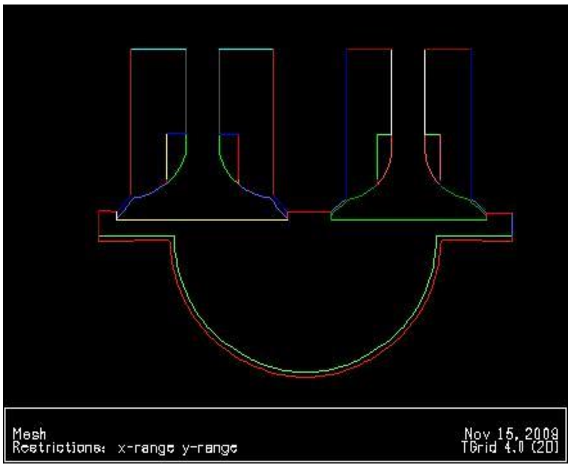


Fig .2. Two-Dimensional model of IC Engine

B) **Meshing of 2D Model**

An ANSA model includes a mesh of nodes and elements. The best way of creating mesh is to create the part's geometry, and then generate a mesh on the geometry. Since the finite element model is associated with the part, any change to the part is automatically reflected in the nodes and elements of the mesh. In mapped mesh the points of the mesh are arranged in a regular way all through the continuum and can be stretched to fit a given geometry where as in free mesh the points fill the space to be considered but is not connected with the regular topology.

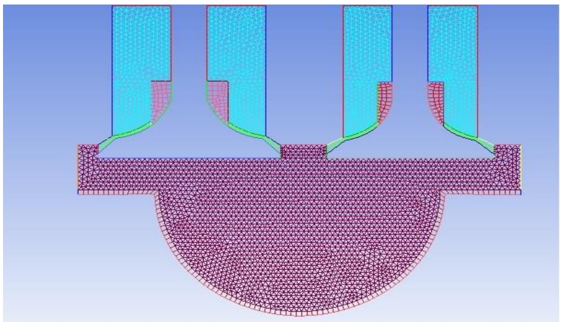


Fig .3. Meshed IC Engine model

C) **Importing the Model to Analyzing Software**

The meshed 2-D IC engine model is than imported to analyzing software such as ANSYS, FLUENT, CFX etc. In this case the FLUENT software is used to analyze the model and hence these designed 2-D IC engine model is imported in FLUENT and further analysis is performed.

D) **Establishing the Intial and Boundary conditions**

Since a finite flow domain is specified, physical conditions are required on the boundaries of the flow domain. The simulation generally starts from an initial solution and uses an iterative method to reach a final flow field solution. The valve timings and temperature of the wall are given as initial and boundary conditions.

E) Performing the Simulation & Monitoring It

The simulation is performed with various possible options for interactive or batch processing and distributed processing. As the simulation proceeds, the solution is monitored until a "converged" solution has been obtained, which is iterative convergence.

F) Post-Processing the Simulation for Results

Post-Processing involves extracting the desired flow properties (temperature, velocity, turbulence, etc...) from the computed flow field.

G) Computational Domain

The 2-Dimensional model shown in figure 2 is used for the analysis. During the solution, as the piston moves, the internal mesh structure deforms automatically to minimize the distortion of each individual cell. Figure 2 and 3 shows the geometry and mesh distribution when piston at a bottom dead center (BDC) and the injection parameters are given in Table III. The starting Crank angle when piston @ BDC is 180^0. For each stroke corresponding crank angle is 180^0c, total for 4 strokes 720^0 CA. Injection starts @ 343^0 CA means, when piston moves from BDC to TDC, the fuel injection starts 17^0 CA before TDC.

TABLE IV
INJECTION PARAMETERS

Type	Direct injection with single central injector
Number of nozzles	2
Total flow rate (g/cycle)	0.05
Start time (CA)	350
Stop time (CA)	370

4. RESULTS AND DISCUSSION:

The ASTM standard tests to determine various physicochemical properties of the base fuels (diesel) as well as the modified fuels were carried out under identical laboratory condition. The primary objectives of this investigation were to determine the variations in the properties of the fuels, due to the addition of the Aluminum oxide (Alumina) nanoparticles and to estimate the effect of the level of inclusion of the additives (dosing level). The combustion performance and the emission characteristics of the diesel engine are investigated. Performance tests were conducted on the diesel engine using the modified fuel samples and compared with those with the base fuels, to determine the engine performance enhancement and the reduction of emissions, due to the addition of the catalyst. The performance parameters, such as BTE (Brake Thermal Efficiency), Brake Specific Fuel Consumption, and the emission characteristics such as NO_x, CO, HC, CO_2 and smoke opacity are plotted against loading condition.

A) Fuel Properties

The flash point of the fuel gives an indication of the volatility of a fuel. The lower the volatility, the higher the flash and fire points. Table IV shows the variation of the flash point of the diesel with modified fuel as a function of the dosing level. As illustrated, the modified fuel shows an increasing trend for the flash point with the dosing level, which indicates a successive decrease in the volatility of the fuel with increases in the quantity of the fuel additive. Higher flash point temperatures are desirable for safe handling of the fuel. The influences of the dosing level of the additive and the temperature on the kinematic viscosity of modified fuel are illustrated in Table IV, which indicates that the viscosity of the fuel decreases with an increase in the temperature for all dosing levels. The change in the viscosity of the fuel affects the engine performance as well as the hydrocarbon emissions. Lower fuel viscosities may not provide sufficient lubrication of fuel injection pumps or injector plungers resulting in leakage or increased wear thus reducing the maximum fuel delivery. This imposes a limitation on the quantity of the fuel additive that can be used to enhance the combustion performance of the fuel. The fuel atomization is affected by the fuel viscosity, and the fuel with higher viscosity tends to form larger droplets on injection, which can cause poor combustion and increased exhaust smoke and emissions.

TABLE V
FUEL PROPERTIES

PROPERTIES	UNITS	DIESEL	DIESEL + 25 PPM AL	DIESEL + 50 PPM AL	DIESEL + 75 PPM AL
Kinematic Viscosity at 40°C,cSt	mm^2/s	896	895	896	896
Density at 15°C	kg/m^3	3.20	3.05	2.98	2.80
Flash Point,	°C	55	57	59.5	62

B) Variation of Cylinder Peak Pressure

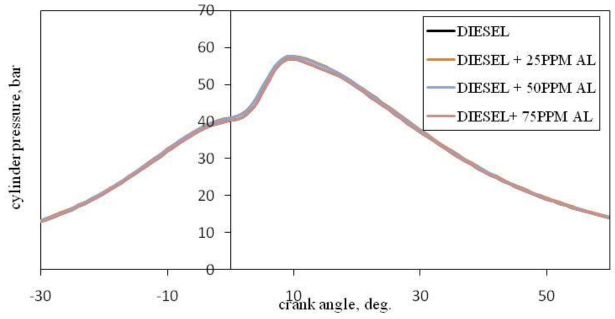


Fig 4: Variation of Cylinder Peak Pressure

The variation of cylinder gas pressure with crank angle is shown in figure 4. It is observed that the peak pressure increases with the addition of aluminum oxide in diesel. The addition of aluminum oxide with neat diesel accelerates early initiation of combustion and the ignition delay decreases, hence more fuel is accumulated in the premixed combustion phase is the cause for faster combustion which results in higher peak pressure. The highest peak pressure is observed as 10.2MPa for the D+75ppm Al blend, whereas is 8.4MPa for neat diesel.

C) Variation of Brake Thermal Efficiency

The variation of Brake Thermal Efficiency with load is shown in figure 5. The results show that the brake thermal efficiency of the diesel engine is improved by the addition of aluminum oxide in the fuel. The Aluminum oxide nanoparticles present in the fuel promote longer and more complete combustion, compared to the base fuel as aluminum oxide acts as an oxygen buffer and thus increases the efficiency.

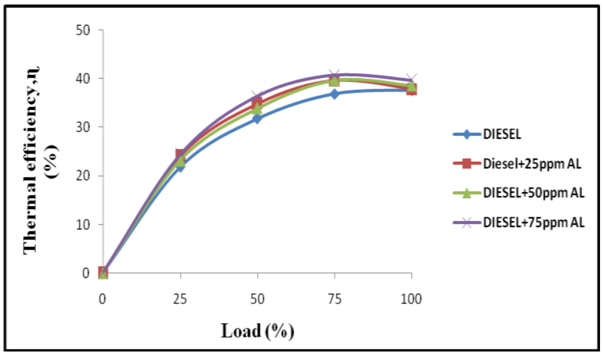


Fig 5: Variation of Brake Thermal Efficiency

It has also been observed that the improvement in the efficiency generally increases with the dosing level of nanoparticles. A maximum brake thermal efficiency was obtained when the dosing level was varied from 25 to 75 ppm, with a maximum improvement observed at a dosing level of 75 ppm. The maximum BTE at the full load is observed as 39.6%.

D) Variation of Brake Specific Fuel Consumption

The SFC is higher for the diesel - alumina nanoparticle blends than neat diesel at all loading condition. The lowest SFC is observed as 0.2240 kg/kW.hr for the D+75ppm Al blend whereas it is 0.23 kg/kW.hr for neat diesel at the load of 75 %. This phenomenon is due to the aluminum oxide addition which promotes combustion.

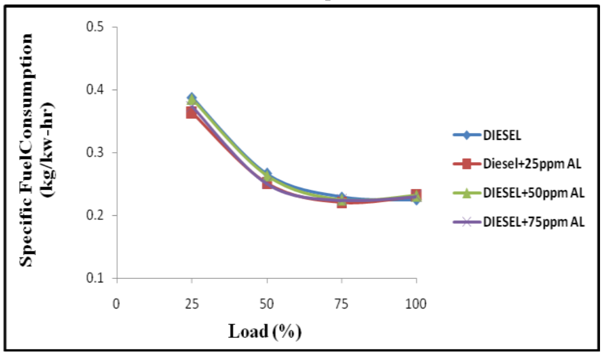


Fig 6: Variation of Brake Specific Fuel Consumption

E) Variation of Nitrogen Oxide (No_x) Emissions

The variation of nitrogen oxide with load is shown in figure 7. The NOx emission is higher for neat diesel when compared to all the fuel blends. The effect of oxygenated additives enhances combustion & The magnitude of NO*x* emission observed is 983 ppm for D+75ppm Al, The reductions in NOx emission is due to complete combustion of modified fuels with the help of catalyst effect of nanoparticle additions which promotes heat transfer in the combustion chamber

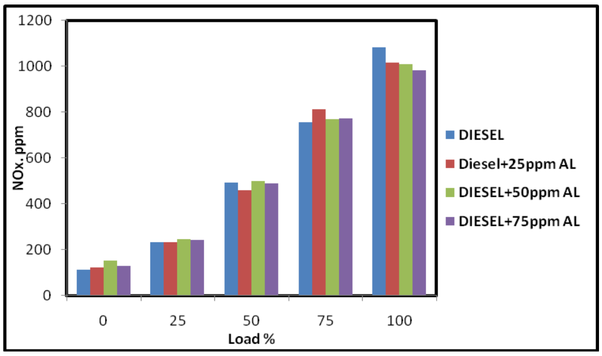


Fig 7: Variation of Nitrogen Oxide (Nox) Emissions

F) Variation of Smoke Opacity

The variation of smoke opacity with engine load is shown in the figure 8. The smoke decreases with diesel – alumina blends when compared with neat diesel. The use of oxygenated fuel improves better combustion is the cause for the smoke reduction. The least smoke is observed as 80 ppm for the D+75ppm Al blend at higher load.

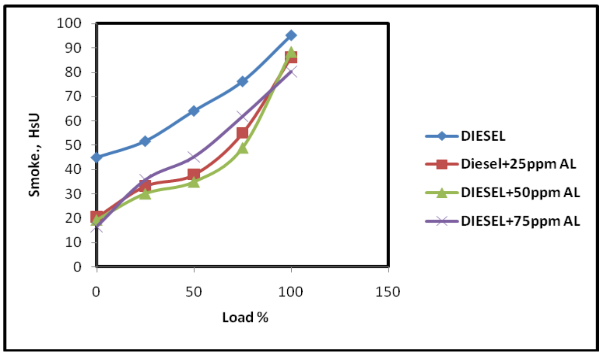


Fig 8: Variation of Smoke Opacity with various blend ratios.

G) Variation of Carbon Monoxide (Co) Emissions

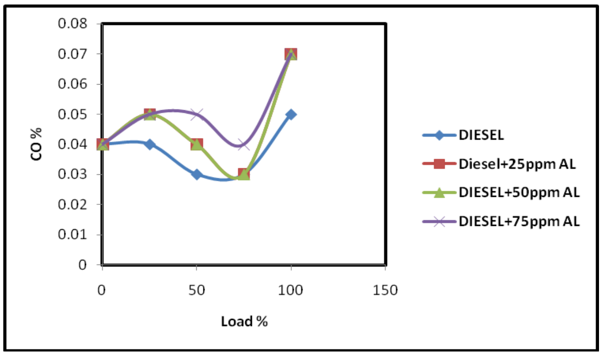


Fig 9: Variation of Carbon monoxide (CO) with various blend ratios

Carbon monoxide (CO) emission of the diesel fuel, which is formed due to incomplete combustion of fuel air-mixture in the combustion chamber was found to decrease with the inclusion of the alumina nanoparticle additives. Figure 9, demonstrates the carbon monoxide (CO) emissions versus engine load with the variation of additive dosage**.** The carbon monoxide emission increases with the use of diesel – alumina blends than neat diesel. The CO emission is marginal up and then increases rapidly with higher load.

H) Variation of Hydrocarbon (Hc) Emissions

The variation of hydrocarbon emission with engine load is shown in figure 10. It is observed that the level of Unburned Hydrocarbon (HC) emission is higher for diesel – alumina blended fuel compared to base engine, this is because the faster evaporation of the blended fuel hence temperature inside the combustion chamber is lower and it leads to high percentage of Hydrocarbon (HC) emission

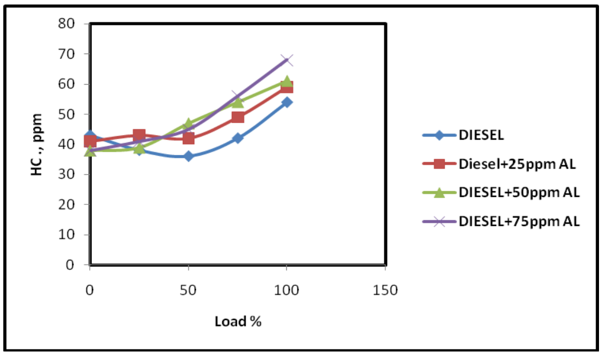


Fig 10: Variation of Hydrocarbon (HC) emission with various blend ratios

I) Variation of Carbondioxide (Co$_2$) Emissions

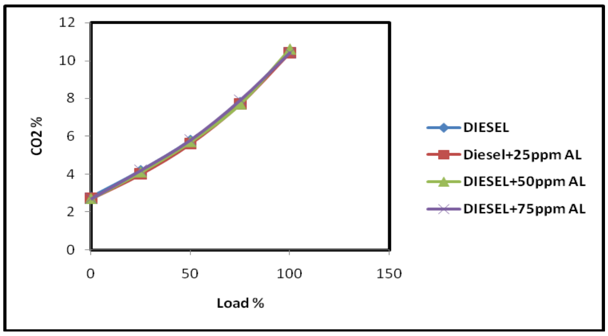


Fig 11: Variation of Carbon dioxide (CO_2) with various blend ratios

The variation of $CO_2$with engine load is shown in the figure 11. It is observed that at all operating conditions the emissions of carbon dioxide is slightly increased while using the diesel – alumina blended fuel compared to conventional diesel fuel. The CO_2 emissions are considered as GHGs (Green House Gases), their higher magnitude indicates the complete combustion in the engine cylinder on par with the reduction of other hazardous emissions such as NO_X, CO, Unburnt HC and Smoke.

J) COMPARISON OF RESULTS

Nox Variations

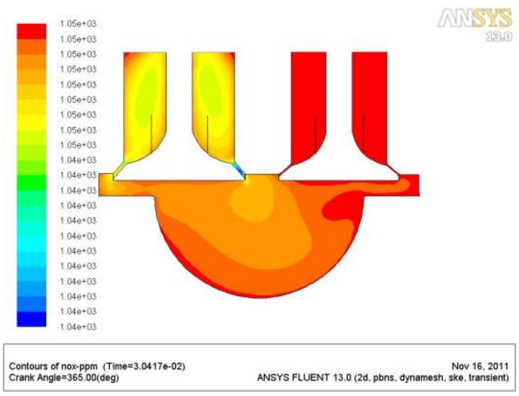
The NO_X from emission test is 983 ppm at 1800 rpm for 75 ppm Alumina blended diesel. The detailed time history of spray, fuel mass fraction and temperature distributions provided by the CFD simulation are valuable towards gaining a better understanding of the features of combustion for given engine configurations.

The temperature distribution inside the cylinder for different crank angles, and NOx emissions are given above. NOx formation is highly sensitive to temperature and also effected by species concentration. Table VI presents the comparison of simulated and measured emission NO_X for various fuel cases. The deviations from experiment and simulation results of NO_X emission are around 4.5 to 13.2 %. It was found that the general agreement between prediction and engine test was reasonable for the base and modified fuels.

DIESEL

25 PPM ALUMINA BLENDED DIESEL

50 PPM ALUMINA BLENDED DIESEL



75 PPM ALUMINA BLENDED DIESEL

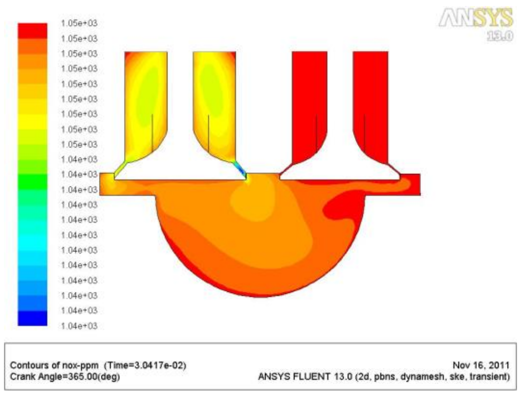


Fig 12 : NO_X Variations at different crank angles for various blend ratios

TABLE VI Comparison of Results

Fuel Used	Experiment	CFD Simulation	% Variations
Diesel	1084	1250 -1270	13.2
25 ppm Alumina Blended Diesel	1016	1090 - 1110	6.7
50 ppm Alumina Blended Diesel	1010	1040 - 1050	4.0
75 ppm Alumina Blended Diesel	983	1030 - 1040	4.5

5. CONCLUSION:

One of the methods to vary the physicochemical properties and combustion characteristics of a hydrocarbon fuel is the use of additives, which are found to be especially effective in nanoparticle form, due to the enhancement of the surface area to volume ratio. Engine performance tests were conducted for diesel and modified fuel by the addition of Aluminum oxide (Alumina) nanoparticles. CFD analyses along with experimental investigations were carried out to compare emissions of diesel and modified fuel. The observations are as follows. The thermal efficiency of modified diesel is higher than pure diesel at all the loads. The NO_X emission is lower for diesel- alumina blends than neat diesel. The smoke opacity decreases with the diesel - alumina blends. The addition of aluminum oxide (alumina) nanoparticles in neat diesel proportionately decreases the smoke further. Temperature profiles as well as NO_X emissions contour from CFD have good agreement with experimentally measured data.The combustion process can be better understood by precise estimation of flame temperature and studying reaction chemistry for using the blended fuel. This is suggested for future work.

REFERENCE

[1].Sadhik Basha, J. and Anand, R.B. (2010a) "Applications of nanoparticle/nanofluid in compression ignition engines – a case study", International Journal of Applied Engineering Research, Vol. 5, pp.697–708.

[2]. Sajith, V., Sobhan, C.B. and Peterson, G.P. (2010) "Experimental investigations on the effects of Cerium oxide nanoparticle fuel additives on biodiesel", Advances in Mechanical Engineering, ID 581407.

[3 Tayfun Ozgur, Mustafa Ozcanli, Kadir Aydin., 2011, "Investigation of nanoparticle additives to biodiesel for improvement of the performance and exhaust emissions in a compression ignition engine", IGEC-VI – 027.

[4] Mohamed Yusuf Ali, M.Masood, S.N.Mehdi., 2010, "A CFD Combustion analysis of Hydrogen – Biodiesel dual fuel system" , World Applied Science Journal 9 (2): 144-150.

[5]. K. Kannan and M. Udayakumar., 2009, "NOx and HC Emission Control Using Water Emulsified Diesel in Single Cylinder Diesel Engine", ARPN Journal of Engineering and Applied Sciences, Vol. 4, No. 8, ISSN 1819-6608.

[6]. R. Bhoobathi , Shaik Amjad , and Dr. R. Rudramoorthy., 2010, "Diesel Engine Combustion Simulation using Computational Fluid Dynamics", Process of International Conference on Advances in Mechanical Engineering : 18-22.

[7]. T.S. Strauss, G.W. Schweimer and U. Ritscher, 1995,
"Combustion in a Swirl chamber Diesel engine Simulation by Computation of Fluid Dynamics," SAE Trans. 104, Section: Journal of Engines, pp.519-530.

[8].C.C.Enweremadu et al, 2011, "Investigation of the relationship between some basic flow properties of shea butter biodiesel and their blends with diesel fuel", International Journal of the Physical Sciences Vol. 6(4), pp. 758-767, 18 February,

[9]. M. T. Naik ,G.Ranga Janardhana, K.Vijaya Kumar Reddy., 2010, "Experimental Investigation into Rheological Property of Copper Oxide Nanoparticles suspended in Propylene Glycol-Water based fluids", ARPN Journal of Engineering and Applied Sciences, Vol. 5, No. 6 : ISSN 1819-6608.

[10] Y. Kidoguchi, M. Sanda and K. Miwa, "Experimental and theoretical optimization of combustion chamber and fuel distribution for the Low Emission Direct – Injection Diesel Engines," Engg for Gas turbines & Power, Vol.125/351, 2003.

[11]. Barman S.C., N. Kumar, R. Singh, G.C. Kisku, A.H. Khan, M.M. Kidwai, R.C. Murthy, M.P.S. Negi, P. Pandey, A.K. Verma, G. Jain, and S.K. Bhargava, 2010, "Assessment of urban air pollution and its probable health impact". J of Envr Biology 31:913-920.

[12]. Selvan A.M.V., Anand, R.B. and Udayakumar, M. (2009) "Effects of cerium oxide nanoparticle addition in diesel and diesel-biodiesel-ethanol blends on the performance and emission characteristics of a CI engine", Journal of Engg and Applied Sciences, Vol. 4, pp.1–6.

[13]. Reitz R.D. and Rootland C.J., 1995, "Development and testing of diesel engine CFD model". Progess. Combustion. Science. vol.21, pp 173196.

[14]. J. Sadhik Basha and R.B. Anand., 2011, "An experimental investigation in a diesel engine using carbon nanotubes blended water-diesel emulsion fuel", Journal of Power and Energy : 225 - 279.

[15]. Kao, M. J., Lin, B. F., and Tsung, T. T., "The Study of High-Temperature Reaction Responding to Diesel Engine Performance and Exhaust Emission by Mixing Aluminum Nanofluid in Diesel Fuel," 18th Internal Combustion Engine Symposium Jeju, Korea, 2005.

[16]. V.J.Mohanraj and Y Chen, 2006, “Nanoparticles – A Review”, Tropical Journal of Pharmaceutical Research, 5 (1): 561-573.

[17]. Usman Asad, Raj Kumar, Xiaoye Han, Ming Zheng., 2011, “Precise instrumentation of a diesel single-cylinder research engine”, Measurement 44: 1261–1278.

[18]. G.D’Errico, D. Ettorre, T. Lucchini., 2007, “Comparison of Combustion and Pollutant Emission Models for DI Diesel Engines”, SAE Technical Paper 07NAPLES - 90.

[19]. K.M.Pandey, D.H.Das and B. Acharya., 2010, “Effects of Variation of Specific Heat on Temperature in Gaseous Combustion with Fluent Software”, International Journal of Environmental Science and Development 5: 419-422.

[20]. Yanan Gan and Li Qiao., 2011, “Combustion characteristics of fuel droplets with addition of nano and micron-sized aluminum particles”, Combustion and Flame 158