Numerical Analysis of Aluminium Oxide Nano Particles with Biodiesel in a Diesel Engine Fitted with Hemispherical Groove in the Piston

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ABSTRACT: For proper combustion, bowl in the piston geometry plays a crucial role when the engine valves are in closed position. In the present work, the combustion geometry is of hemispherical groove in the upper region of the piston. Simulations were conducted for different blends (b20+al40, b20+al80) to analyze the combustion features in a four stroke diesel engine using ansys r18.1 software considering above geometry of the piston. Pertaining to greater amount of density, viscosity of biodiesel blends, variations for b20+al80 render more performance than the biodiesel. Turbulent kinetic energy of both the fuels follow similar trend due to proper mixing of air with the fuel from fuel injector.

KEYWORDS: simulation, combustion features, diesel engine, biodiesel blends, grooved hemispherical combustion chamber

ACRONYMS AND NOMENCLATURE
HCC Hemispherical Combustion Chamber
SCC Shallow Depth Combustion Chamber
TCC Toroidal Combustion Chamber
CNT Carbon Nano Tubes
Bsfc Brake Specific Fuel Consumption
CR Compression Ratio CR
B20+Ag40 200ml Biodiesel + 800ml Diesel + 40 ppm silver nano particles
B20+Ag80 200ml Biodiesel + 800ml Diesel + 80 ppm silver nano particles

I. INTRODUCTION
Rao et al [1] have developed a numerical model with three different shapes of piston bowl: hemispherical, shallow depth and toroidal combustion chamber with a particular compression ratio for all the bowl geometries. Better design was suggested to analyse and optimize the model based on the emission and performance features. Though, torroidal shape offered better results in terms of ISFC as well as soot among the three, NOx emissions are found to be higher for that particular bowl shape.

Ghanbari et al [2] explored on the effectiveness as well as emission features of a DI functioning on diesel blends with nano additives. MWNT's, Nano particles of silver with different ppm were prepared and mixed as additives to the biodiesel. When a DI was run with these combinations at various speeds, Results conveyed that with the addition of nano particles in diesel as well as biodiesel fuels, there is an increase in power as well as
torque up to 2% and decrease in brake specific fuel consumption (bsfc) upto 7.08% compared to the conventional diesel fuel.

They also found that Carbon monoxide emissions for this combination was less when compared to conventional diesel as fuel. Unburned hydrocarbon emissions were found to be reduced for biodiesel added with silver nano particles. Blends mixed with nano particles of MWCNT showed a value of maximum. NOx emission were found to be increased with the addition of Nano particles in both the cases in contrast to the conventional diesel.

Hosamani [3] analyzed the influence of various blends as well as compression ratio on combustion aspects under different load condition with a fixed increment each time. It was found that the blends executed higher cylinder pressures and lesser rate of heat release. It was also observed that there was a higher increase in pressure which lead to increase in the combustion duration. Combustion efficiency increased with the increment in compression ratio.

Karunanidhi et al [4] carried out numerical analysis to analyse the combustion as well as emission features of various combustion chambers. From the outcomes of the analysis, it was observed that combustion chamber of hemispherical type was found to be more effective than the shallow depth type as it produces greater pressure and temperature. But with the increase in the temperature, there is a tendency for the increase in NOx emissions as well as soot formation

Nanlohy et al [5] carried out experimental studies on the combustion features maintaining jatropha oil under room temperature in the presence and absence of a catalyst. The conclusions from the experiments says that the catalyst plays a crucial role in reducing the time of ignition and burnout. Also the existence of the the catalyst modifies and diminishes the arrangement of the geometry of triglyceride so that both the viscosity as well as flash points are lowered. With this the fuel engrosses more heat well and it becomes more flammable.

Matthew Jones et al [6] carried out studies on the phenomenon of combustion with nano aluminium and aluminium oxide particles substantially suspended in ethanol which is utilized as a subsidiary energy transporter. Experiments were conducted with different volume fractions of nano aluminium and nano aluminium oxide particles. Results revealed that the enhancement in concentration of aluminium nano sized particles, aluminium oxide nano particles result in increase in the quantity of heat released. Also the results depicted that there is an augmentation in heat of combustion with respect to the corresponding enhancement in the concentration of the nano particles.

Gan [7] carried out analytical studies on flaring features of fuel constituting aluminium particles which are of the size of nano and micro level. The results obtained described about the various features of the particle sedimentation, which are accountable for the dissimilar conduct that was noticed in the experiments.

Ozugari et al [8] have studied the effectiveness, emission features,combustion phase of engine operating on blends of H2-diesel of different volumetric ratios in comparison with the conventional diesel fuel. Simulations carried out to analyse the performance, emission behaviour revealed that addition of hydrogen to diesel blends enhanced both the performance, the emission features in the engine.

Taib et al [9] simulated for different diesel-ethanol- Pongamia Methyl Ester blends in a Yanmar TF90 compression ignition engine using a commercial CFD software. Blending ethanol and Pongamia Methyl Ester in conventional diesel enhanced the rate of release of heat during combustion. This improved the efficiency of the engine. They also stated that there is a certain limit over which the blend containing ethanol is not suitable for direct injection engines without any alterations. This is because of the low rate of heat release and temperature for the ethanol blends.

Taib et al [10] studied the influence of different strategies related to injection and different parameters like CRand AIT, alterations on ignitibility of blends, combustion features as well as emissions.They carried out simulations using a commercial CFD software to analyze the effect of diesel ethanol pongamia methyl ester blends under different boundary conditions. Results showed that with the increase in mass of injection and reducing the duration of injection has no crucial role to play on ignition phenomenon.

II. COMBUSTION GEOMETRY MODEL MESHING

Figure 1 & 2 shows the three dimensional geometry of combustion domain. Geometry of combustion space is of the type bowl in piston with hemi-spherical channel in the upper portion of the piston. To initiate combustion, the bowl in piston geometry plays an important role, when inlet, exhaust valves are in closed position at the end of compression stroke.
III. COMBUSTION MODELING AND DEVELOPMENT

In this study, conservation of mass, momentum, energy, turbulence, species transport governing equations are used to analyze the combustion in DI diesel engine with appropriate boundary conditions. RNG k-ε model is utilized in solving the Navier Stokes equations. Governing equations considered in the present model are droplet energy, equation of motion and spray equations. For discretization of model equations, the upwind scheme is used in the present study. Ansys fluent software is used to solve the governing, algebraic equations which can be solved numerically [11, 19].

3.1 Turbulent Kinetic Energy Model
Fluctuations of velocity field in the engine influences the turbulence. RNG k-ε model [11] was used in the present study for modeling the turbulence. [11],[12] Statistical technique was used to derive RNG k-ε model. This model is similar to standard k-ε model, but swirling effects are included in the internal combustion engine analysis.[13,14] RNG k-ε model transport equations are represented in the following form as equations (1) & (2):

\[
\frac{\partial \rho k}{\partial t} + \nabla (\rho \vec{u} k) = \nabla \cdot \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \nabla k \right] + P_k - \rho \varepsilon \tag{1}
\]

\[
\frac{\partial \rho \varepsilon}{\partial t} + \nabla (\rho \vec{u} \varepsilon) = \nabla \cdot \left[ \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \nabla \varepsilon \right] + C_{1}\beta \frac{\varepsilon}{k} - C_{2}\rho \frac{\varepsilon^3}{k} \tag{2}
\]

Where

\[
C_{2}\varepsilon = C_{2}\varepsilon + \frac{C_{1}\mu \eta^3 (1 - \eta^4/\eta_0)}{1 + \beta \eta^3}
\]

Where \( \rho \) is density, \( \mu \) is viscosity, \( u \) is velocity

3.2 Combustion Modeling

[15] Eddy dissipation concept (EDC) was included in the combustion model, which is use in the Fluent code during analysis. Chemical reactions are modeled by considering volumetric reactions takes place inside the cylinder and on the wall surfaces [16, 20]. General form of governing equation is represented in the following form as equation (3):

\[
\frac{\partial \rho Y_i}{\partial t} + \nabla \cdot (\rho \vec{v} Y_i) = -\nabla \cdot \vec{J}_i + R_i + S_i
\]

(3)

Where \( Y_i \) is mass fraction of selected species, \( R_i \) is rate of production, \( S_{li} \) is rate of creating by adding phase of dispersion. \( S_{ct} \) is turbulent Schmidt number

3.3 Ignition Modeling of the Engine

[17] For simulating DI diesel engine, auto ignition model (Hardenurg) model is used in the current study. The equation considered for species is represented in the following form as equation (4):

\[
\frac{\partial \rho Y_{ig}}{\partial t} + \nabla \cdot (\rho \vec{v} Y_{ig}) = -\nabla \cdot \left( \frac{\mu_s}{S_{ct}} (Y_{ig}) \right) + \rho S_{ig}
\]

(4)

3.4 Spray Break Up Model

[18] The TAB model depends on the distorting and oscillating droplet and spring mass system. The governing equation for damped and forced oscillation is represented in the following form as equation (5):

\[
F - kx - d \frac{dx}{dt} = m \frac{d^2 x}{dt^2}
\]

(5)

The coefficients for the above equation is represented in the following form as equation (6) and displacement of the droplet equator are taken from Taylors analogy.
\[
\frac{F}{m} = C_g \frac{\rho_i \mu^2}{\rho r}, \quad \frac{k}{m} = C_i \frac{\rho}{\rho r^3}, \quad \frac{d}{m} = C_d \frac{\mu_i}{\rho r^2}
\]

(6)

Where \( \rho_i \) and \( \rho_g \) are discrete phase and continuous phase densities, \( r \) is droplet radius, \( \mu_i \) is droplet viscosity.

3.5 Modeling Drop Collision

Tracking of fuel droplets and calculating the number of collisions are included in the drop collision model and their outcomes are effectively computed. [18] O’Rourke’s method forms the basis for Droplet collision model, which is based on approximation of stochastic collision. Each outcome probability was determined from the Weber number. The Weber number is represented in the following form as equation (7)

\[
W_e = \frac{\rho V_r^2 l}{\sigma}
\]

(7)

Where \( l \) is arithmetic mean diameter, \( V_r \) is relative velocity between two parcels, \( \sigma \) is surface tension.

3.6 Modeling Wall Film

When the fuel is dispersed in the combustion space, it impinges upon the piston. The Influence of deposits of carbon over the areas inside the combustion space will be taken care by Wall film modeling. Ansys Fluent used the concept of single fuel droplet impinged on the surface boundary and forms thin layer. It is observed that, deposits of carbon over the surfaces absorbed the layer of fluid in the later cycle.[19,20]. Energy, boiling temperature of the liquid constitute the main variables for fuel droplet impingement and its detachment criteria. The impact energy is represented in the following form as equation (8)

\[
E^2 = C_{2e} + \frac{\rho V_r^2 l}{\sigma} \left( \frac{1}{\min(h_o / D,1) + \delta_{bl} / D} \right)
\]

(8)

\( D \) represents diameter of the droplet, \( V_r \) is velocity relative to the particle, \( \delta_{bl} \) represents the thickness of the boundary layer.

IV. RESULTS & DISCUSSIONS

![Figure 3: Temperature contours with Diesel](image)
Figure 4: Temperature contours with B20+Ag40

Figure 5: Temperature contours with B20+Ag80

Figure 6: Mass Fraction of Nox for Diesel
Figure 7: Mass Fraction of Nox for B20+Ag40

Figure 8: Mass Fraction of Nox for B20+Ag80

Figure 9: Mass Fraction of soot and Diesel
In conjunction with pressure behavior during the engine operation, the temperature takes a similar behavior to the pressure as represented in Fig 12 and 13, the temperature is reduced in the extension and rise in the compression and auto ignition similarly.
From the Fig 6,7,8,9,10 and 11, it could be observed that Nox emissions are higher for B20+Ag80 than for B20+Ag40 and diesel.

V. CONCLUSIONS

The contour diagrams of predicted Temperature for Nox and Soot for diesel, B20+Ag40, and B20+Ag80 are represented in Figure (6),(7),(8),(9),(10),(11) respectively. Pertaining to greater amount of density, viscosity of bio-diesel blends, variations for B20+Ag80 are more than the diesel.

- Due higher variation in viscosity, combustion gas velocity for B20+Ag80 is more than that of diesel oil.
- Turbulent kinetic energy of both the fuels follows similar trend by virtue of proper mixing of air with the fuel from fuel injector.
- B20+Ag80 can be used as alternative fuel to diesel oil, without any modifications to the DI diesel engine.
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