DESIGN & ANALYSIS ON A DIESEL ENGINE BY IMPLEMENTING TANGENTIAL GROOVES ON PISTON FOR COMBUSTION IMPROVEMENT THROUGH CFD

K.S.Karunakar[1], Dr. C. Vijaya Bhaskar Reddy[2], D.S. Jaheer Basha[3], M. Sivaramakrishnaiah.

PG – Scholar, Department of Mechanical Engineering, SVCET (Autonomous), Chittoor, A.P, INDIA - 517127.

Professor & HOD, Department of Mechanical Engineering, SVCET (Autonomous), Chittoor, A.P, INDIA - 517127.

Assistant Professor, Department of Mechanical Engineering, SVCET (Autonomous), Chittoor, A.P, INDIA - 517127.

Assistant Professor, Department of Mechanical Engineering, SVCET (Autonomous), Chittoor, A.P, INDIA - 517127.

Abstract - *The complete combustion appears to be most prominent way to improve the fuel efficiency and to decrease the emission from diesel engines. The present work deals with a new kind of piston modification. Tangential swirling grooves were made on flat surface with centered bowl Piston for better combustion process by increasing swirl in diesel engine. Due to the extreme conditions inside a DI-Diesel engine, when high viscosity diesel is injected into hot air present in the combustion chamber at the end of TDC becomes a problem in mixing the fuel with air for proper combustion. Experimental techniques are sometimes limited in approaching the above mentioned problem. Alternatively, computer simulations (like: Computational Fluid Dynamics) offer the opportunity to carry out repetitive studies on various parameters with clearly defined boundary conditions in order to investigate different configurations. This project is an attempt to create swirling motion of the compressed air in the combustion chamber by preparing some internal grooves on the piston. Creating more swirl motion in combustion chamber tends to make the fuel and air as homogeneous mixture which leads to improve the combustion of fuel. Our simulations results that the swirl generated inside the chamber is more by using piston with tangential grooves and hence the complete combustion is achieved along with reduced emissions.*

Key Words: *CFD Simulation, CATIA V5 Software, Tangential grooves, Swirl, Tumble, Cross Tumble Coefficients.*

1. INTRODUCTION

Combustion and fluid flow modelling in a diesel engine presents one of the most challenging problems. This is due to large density variations where, the fluid motion inside a cylinder is turbulent, unsteady, non-stationary both spatially and temporarily. The combustion characteristics were greatly influenced by the details of the fuel preparation and the fuel distribution in the engine cylinder, which was mainly controlled by the in-cylinder fluid dynamics. The fuel injection introduces additional complexities like two phase flows. Pollutant emissions were controlled by the turbulent fuel–air mixing and combustion processes. A detailed understanding of these processes is required to improve performance and reduce emissions without compromising the fuel economy. From the literature, several researchers performed experimental and numerical studies towards the parameter optimization, fluid mechanics and combustion phenomena. Combustion improvement on a direct injection diesel engine by implementing tangential swirling grooves by: Ritesh Kumar (121116145) Kartikpaliwal (121116139) faculty advisor:- Dr. Rajesh Gupta [1]. A numerical investigation on swirl generation by a helical intake port and its effects on in-cylinder flow characteristics with axisymmetric piston bowls in a small four-valve direct injection diesel engine. The novelty of this study is in determining the appropriate design and orientation of the helical port to generate high swirl. A commercial CFD software STAR-CD is used to perform the detailed three dimensional simulations. Preliminary studies were carried out at steady state conditions with the helical port which demonstrated a good swirl potential and the CFD predictions were found to have reasonably good agreement with the experimental data taken from literature. For transient cold flow simulations, the STAR-CD code was validated with Laser Doppler Velocimetry (LDV) experimental velocity components' measurements available in literature [2].

C.V. Subba Reddy1,*, C. Eswara Reddy2 & K. Hemachandra Reddy The effect of three different sizes of tangential grooves on piston crown on the performance and emission characteristics are studied. Brake specific energy consumption decreases and thermal efficiency of engine slightly increases when operating on blended fuel of 20% Cotton seed oil methyl ester (COME) and 80% diesel (20BD) than that operating on diesel fuel [3]. Stephenson et al. conducted a parametric study on the effects of swirl, initial turbulence, oxygen concentration and ignition delay on fuel vaporization, mixing and combustion process [4]. Chen et al. simulated the transient flow for the induction stroke using STAR-CD software and observed that the standard k-� model with wall function for description of boundary layer behaviour predict the fully turbulent flow inside the cylinder [5]. Payri et al. [6] and Auriemma et al. [7] made in-cylinder measurements under motoring conditions in a light duty diesel engine equipped with a re-entrant bowl in piston combustion chamber. Tangential and radial components of the air velocity were obtained over a crank angle range of 90o above TDC. Estimates of the mean motion, integral time scale and Reynolds shear stress are also found to be comparable with the computational work.

For CI engines arrangement is made such that air inside the cylinder is flown past the injector for proper mixing which involves various methods to produce swirl.

- Some of the common methods used are induction swirl, divided chamber, etc.
- CI engines have different shapes of piston head which create turbulence.

1.1. SWIRL AND TUMBLE COEFFICIENTS

Both swirl and tumble flows are commonly characterized by a dimensionless parameter employed to quantify rotational and angular motion inside the cylinder, which are known as swirl and tumble ratios, respectively. These values are calculated by the effective angular speed of in-cylinder air motion divided by the engine speed. The effective angular speed is the ratio of the angular momentum to the angular inertia of moment. The mass center of the charged in-cylinder air is considered as an origin for the calculation. The three variables (swirl, sideways tumble, and normal tumble ratio) investigated in this paper are presented in the non-dimensional form by applying the equations as follows:

$$SR = \frac{60Hz}{2\pi Iz\omega}$$

$$TRX = \frac{60Hx}{2\pi Ix\omega}$$

$$TRy = \frac{60Hy}{2\pi Iy\omega}$$

Where, Hx, Hy and Hz are the angular momentum of the in-cylinder gas about the x-axis, y-axis and z-axis, respectively. Ix, Iy and Iz are the moment of inertia about the x axis, y axis and z axis, respectively. In addition, ω is the crankshaft rotation or engine speed in the unit of rotation/minute.

1.2. SWIRL MOTION OF AIR IN ENGINE CYLINDER

In a Diesel Engine, air is drawn in to the cylinder during suction stroke and compressed during compressed stroke, due to this compression, pressure and temperature of increase. During the latter part of compression, air is given a certain part of motion just before reaches TDC, fuel is injected in the form of fine spray which contains drops of different sizes and dispersed in the air mass and auto- ignite.

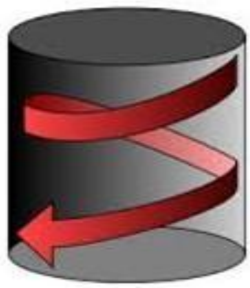

Fig-1: *Swirl motion of air in Engine cylinder*

1.3. TUMBLE MOTION OF AIR IN ENGINE CYLINDER

As the piston reaches TDC the squish motion generates a secondary flow called tumble, where rotation occurs in a circumferential axis near the outer edge of the cavity or piston bowl

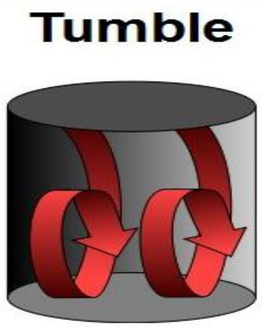

Fig-2: *Tumble motion of air in engine cylinder.*

1.4. AIR MOTION IN DIESEL ENGINE

In a Diesel Engine, the main problem in connection with combustion is the intimate mixing of air and fuel and time available for mixing and combustion is less particularly in the case of high speed Engines. The air motion helps mixing and combustion of fuel and improves the Engine performance and reduces emissions.

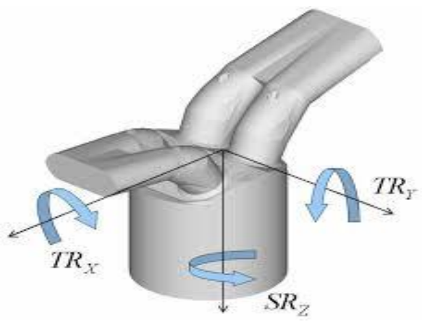

Fig-3: *Air Flow with respect x, y, z-axis.*

2. EXPERMENTAL DETAILS

2.1. Experimental System and Description

The experimental set up consists of single cylinder 4-stroke DI Diesel engine with 87.5 bore diameter, 110mm stroke length, rated speed1500 rpm, BHP/5.2KW rated power and water cooled engine.

2.2.1. LIST OF PARAMETERS INVESTIGATED ON DIESEL ENGINE BY IMPLEMENTING WITH & WITHOUT GROOVES THROUGH CFD SOFTWARE

- *Swirl ratio (v/s) Crank angle*
- *Tumble ratio (v/s) Crank angle*
- *Cross tumble ratio (v/s) Crank angle*
- *Pressure (v/s) Crank angle*
- *Temperature (v/s) crank angle*
- *Fuel (Mass fraction) (v/s) Crank angle*

2.2.2. EQUIPMENT/SOFTWARES USED

1. **FOR DESIGNING THE PISTON**
   - *CATIA V5 SOFTWARE IS USED*
2. **FOR ANALYSIS OF IC ENGINE**
   - **FOR DESIGN, MESHING & ANALYSIS**
     - *ANSYS WORK BENCH*
     - *ANSYS FLUENT*

2.3. SPECIFICATION OF TANGENTIAL GROOVES & CIRCULAR BOWL ON PISTION

Table- *1*: *Specification of tangential grooves*

S.NO	TYPE	BREADTH	DEPTH
1.	*TANGENTIAL GROOVES*	*7.5MM*	*2MM*

Table -2: *Specification of circular bowl*

S.NO	TYPE	RADIUS	DEPTH
1.	*PISTON BOWL*	*50MM*	*25MM*

2.4 SPECIFICATIONS OF THE ENGINE

Table -3: *Specification of the engine*

S.NO	DESCRIPTION	DETAILS
1.	Type of engine	Direct injection Diesel engine
2.	Number of strokes	4-stroke
3.	Numbers of cylinders	Single cylinder
4.	Bore diameter in mm	85
5.	Stroke diameter in mm	110
6.	Crank shaft speed in RPM	1500
7.	Starting crank angle in Degrees	0
8.	Crank period in Degrees	720
9.	Crank angle step size	0.25
10.	Crank radius in meters	0.055
11.	Connecting rod length in meters	0.234
12.	Piston pin offset in meters	0
13.	Piston stroke cut off in meters	0
14.	Minimum valve lift in meters	0.0001

Fig-4: *Tangential swirling grooved piston.*

2.5 EXPERIMENTAL PROCEDURE

As per engine specifications the piston is designed through CatiaV5 software according to engine and imported the design in Ansys Work Bench software for meshing and modeling. Then meshing file is imported into CFD FLUENT software for analysis of diesel engine combustion by giving engine parameters as input and then the reading is consider for every 5Deg crank angel is noted for piston with and without grooves.

1. *Design of normal piston with and without grooves using Catiav5 software.*
2. *The designed piston with and without grooves are imported into CFD FLUENT software.*
3. *Then engine with specifications according to our requirement was imported.*
4. *Then we have simulated designed piston with and without grooves separately for every 5 degrees of crank angel.*
5. *Recorded the simulated values which were generated through software.*
6. *Compared the simulation results between modified tangential piston with normal piston.*

3. RESULTS AND DISCUSSIONS

Experiment was conducted on ANSYS CFD Software on DI Diesel engine, for piston with and without grooves. The main objective was achieved by increasing the swirl motion inside the combustion chamber for better combustion and homogeneity of air and fuel mixture to increase the efficiency of the engine and to decrease the emission rate so the pollution also decreases.

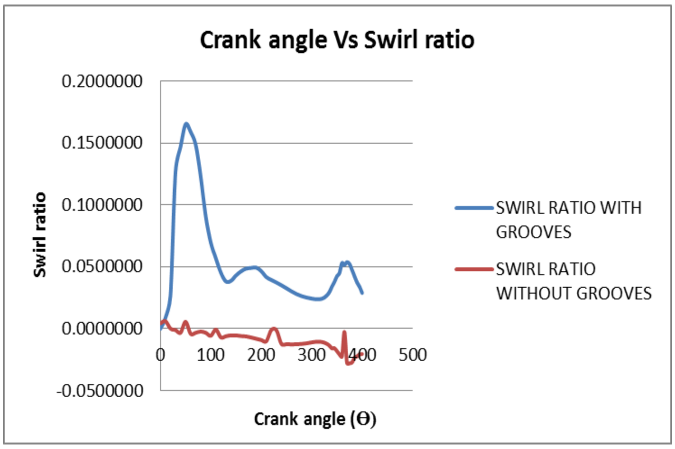

Chart-1: *swirl ratio Vs crank angel for piston with and without grooves*

The swirl ratio is observed to begin with a positive tendency, the maximum swirl achieved around 80˚ crank angle after TDC, and gradually decreased. During the power stroke, swirl flow again starts increasing for piston with groove. For without grooves swirl ratio is observed to begin with a positive tendency, Maximum swirl is achieved around 30˚ crank angle after TDC as seen in chart-1. Beyond this point the swirl ratio gradually decreases towards negative swirl at the end of the suction stoke. The trend continues into the compression stroke due to the friction at the cylinder wall. During the power stroke, swirl flow again starts increasing for piston without grooves as show in chart-1.

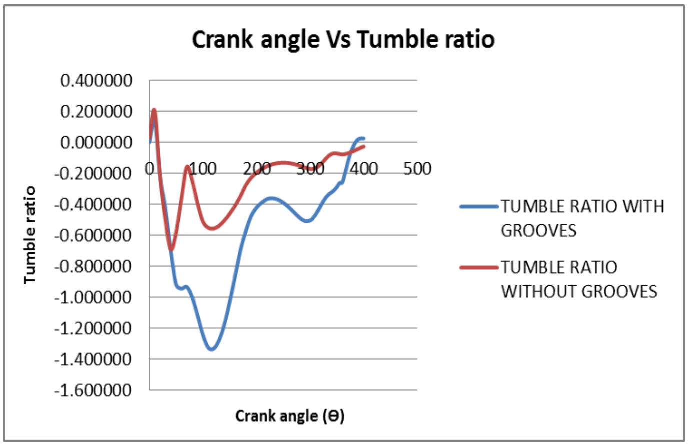

Chart-2: *Tumble ratio Vs crank angel for piston with and without grooves*

The tumble ratio is observed to begin with a positive tendency, the maximum tumble achieved around 20˚ crank angle after TDC, and gradually decrease to negative flow. During the power stroke, tumble flow again starts increasing for piston with groove. For without grooves tumble ratio is observed to begin with a positive tendency, Maximum tumble is achieved around 30˚ crank angle after TDC as seen in chart-2. Beyond this point the tumble ratio gradually decreases towards negative flow at the end of the suction stoke. During the power stroke, swirl flow again starts increasing for piston without grooves as show in chart-2.

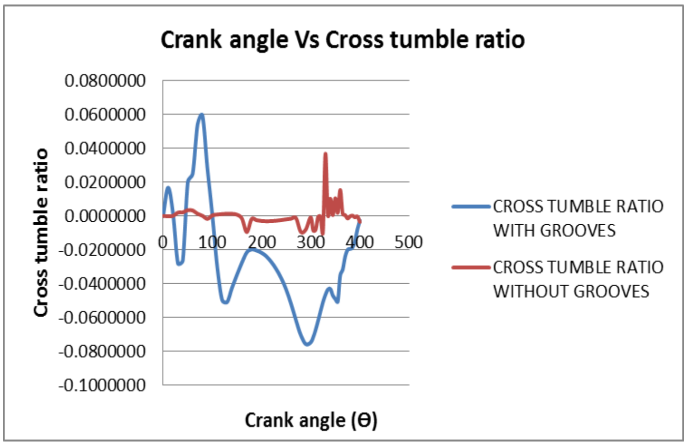

Chart-3: *Cross Tumble ratio Vs crank angel for piston with and without grooves*

The chart shows the cross tumble ratio and its variation inside the cylinder. The maximum CT ratio for piston with grooves is achieved around 90˚ crank angle after TDC, and starts decreasing till the suction stroke. Again cross tumble starts increasing from power stroke. The chart shows crosses tumble ratio for piston without grooves and its variation inside the cylinder. The maximum CT ratio for is achieved around 60˚crank angle after TDC, as shown in chart and starts decreasing till the suction stroke. Again cross tumble starts increasing from compression as well as for power stroke as shown in chart-3.

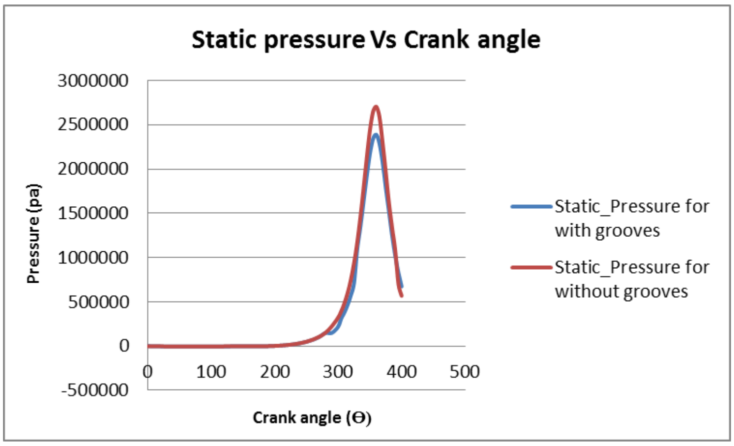

Chart--4: *Pressure vs crank angel for piston with and without grooves*

The chart shows the pressure generated inside the cylinder. The maximum pressure generated for piston with grooves is achieved around 360˚ crank angle after TDC during power stroke then gradually decreased. The pressure generated inside the cylinder, the maximum pressure generated for piston without grooves is achieved around 360˚ crank angle after TDC during power stroke then gradually decreased as shown in chart-4.

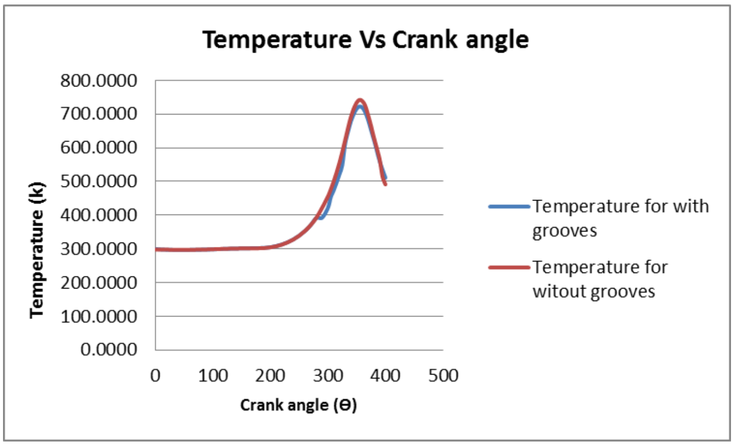

Chart-5: *Temperature vs crank angle for piston with and without grooves.*

The chart shows the temperature generated inside the cylinder. The maximum temperature generated for piston with grooves is achieved around 340˚ crank angle after TDC during combustion then gradually decreased. The temperature generated inside the cylinder. The maximum temperature generated for piston without grooves is achieved around 340˚ crank angle after TDC during combustion then gradually decreased as shown in chart-5.

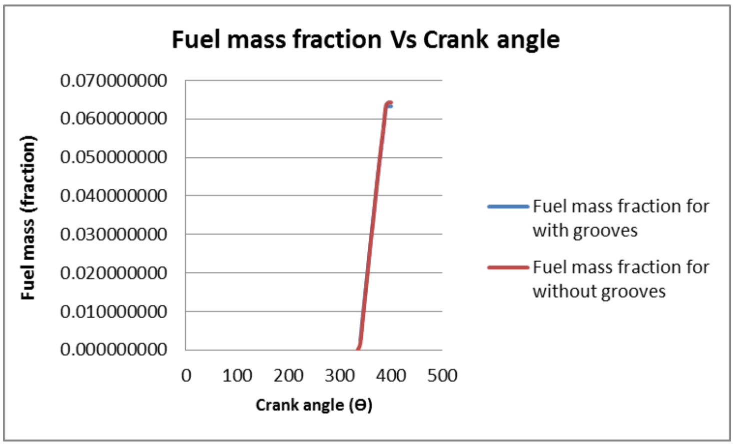

Chart-6: *fuel (mass fraction) vs crank angel for piston with and without grooves*

The chart shows the fuel mass fraction consumed inside the cylinder. The maximum fuel mass fraction consumed for piston with grooves is achieved around 380˚ crank angle after TDC during combustion then remains same. The maximum fuel mass fraction consumed for piston without grooves is achieved around 380˚ crank angle after TDC during combustion then remains same as shown in chart-6.

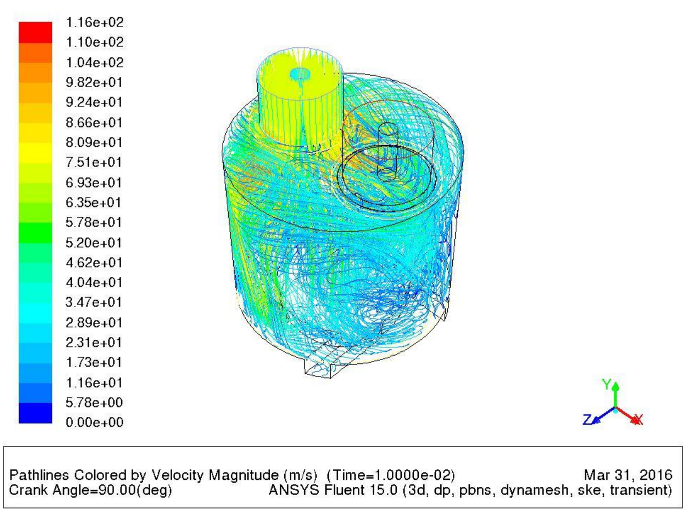

Fig-5: *CFD simulation for velocity path inside the cylinder*

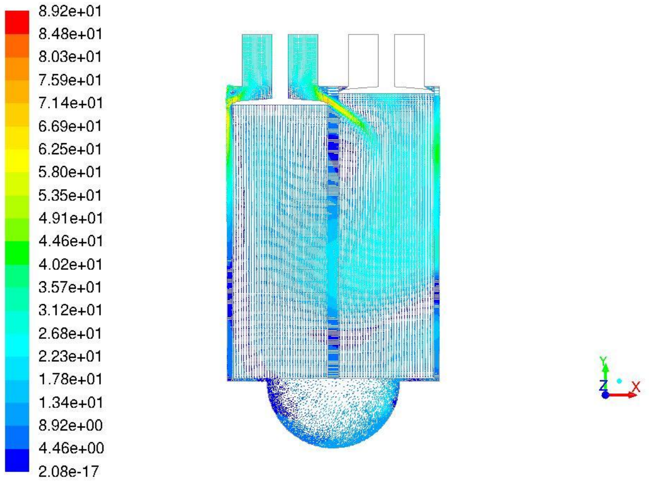

Fig-6: *CFD simulation for velocity vector inside the cylinder*

4. CONCLUSION

Based on the values obtained from the CFD Analysis through diesel engine for both with and without grooves, The following conclusion are made The varied piston geometry of tangential port enhances the turbulence and this is due to better mixing of air-fuel, the thermal efficiency is increased and whereas specific fuel consumption and soot emissions are reduced. This is one of the major compromises of the swirl flows, that are the requirement of large inlet valve for larger suction of air flow during high engine RPM and the requirement of smaller inlet valve for better swirl intensity generation.so their exits an optimal ratio for both swirl, tumble and cross tumble flows.

The performance of the engine falls beyond optimal ratios due to the decrease in volumetric efficiency, even though, the swirl, tumble and cross tumble intensities are very high. This study show that in –cylinder CFD predication yield a responsible result that allows improving the knowledge of the in-cylinder flow pattern and characteristics during intake and compression strokes instead of using the experimental test by practical image The NOX emissions are reduced because of better mixing and a faster combustion process. Swirl motion in the combustion chamber at the end of compression stroke

The swirl, tumble and cross tumble has been increased for piston with tangential grooves so that the better mixture of air and fuel takes place for complete combustion.

REFERENCES

[1] Combustion improvement on a direct injection diesel engine by implementing tangential swirling grooves by: Ritesh Kumar (121116145) Kartikpaliwal (121116139) faculty advisor:- Dr. Rajesh Gupta.

[2] Vamshi Krishna Dawat, Ganesan Venkitachalam, Influence of a High-Swirling Helical Port with Axisymmetric Piston Bowls on In-Cylinder Flow in a Small Diesel Engine, 2016-04-05, Technical Paper 2016-01-0587.

[3] C.V. Subba Reddy1,, C. Eswara Reddy2 & K. Hemachandra Reddy Effect of Tangential Grooves on Piston Crown of Diesel Engine with Preheated Cotton Seed Oil.*

[4] Stephenson, P.W., Clay baker, P.J., Rutland, C.T., Modelling the effects of intake generated turbulence and resolved flow structures on combustion in direct injection diesel engine. SAE Paper No. 960634.

[5] Chen, A., A. Veshagh, S. Wallace, Intake flow predictions of a transparent direct injection diesel engine. SAE Paper No. 981020.

[6] Payri, F., J. Benajes, X. Margeo, A .Gil, CFD modelling of the in-cylinder flow in direct injection diesel engine. Computers & Fluids; vol (33), 2004, p. 995–1021.

[7] Auriemma, M., F.E. Corcione, R. Macchioni, G. Valentino, Interpretation of air motion in re-entrant bowl in-piston engine by estimating Reynolds stresses. SAE Paper No. 980482.

Author (s) E-mail:

1. mytikarunakar@gmail.com ;

2. bhaskarreddychalla@gmail.com

3. jaheerbasha308@gmail.com ;

4. malayathisiva@gmail.com.