

CFD Analysis of Intake Valve for Port Petrol Injection SI Engine

K.M Pandey¹

¹ NIT Silchar, India.

Received: 12 December 2011 Accepted: 1 January 2012 Published: 15 January 2012

Abstract

The air standard efficiency for SI engine is approximately 60

Index terms— Swirl, turbulence intensity, swirl ratio.

1 Introduction

The engine cycle of typical internal combustion engines consist of four consecutive processes as intake, compression, expansion (including combustion) and exhaust. Of these four processes, the intake and compression stroke is one of the most important processes which influences the pattern of air flow structure coming inside cylinder during intake stroke and generates the condition needed for the fuel injection during the compression stroke. As a result of the high velocity inside the internal combustion engine (ICE) during operation, all in cylinder flows are typically turbulent. The exception to this is the flows in the corners and small crevices of the combustion chamber where the close distance of the walls diminished out turbulence. Heat transfer, evaporation, mixing and combustion rates all increase as engine speed increases. This increases the time rate of fuel evaporation, the mixing of the fuel vapor and air as well as combustion process. Fluid motion within the engine cylinder is one of the major factors that control the fuelair mixing and combustion process in spark ignition engines. It also has a significant impact on heat transfer. Both the bulk fluid motion and the turbulence characteristics of the flow are essential to produce the homogeneity structure of air flow come into cylinder. Generally, the initial in-cylinder flow pattern is set up by the intake process and then be substantially modified during compression process. The small-scale mixing of turbulence with compressible flows is represented by the turbulence kinetic energy and turbulence kinematic viscosity. Turbulence inside the cylinder is high during the intake and then decreases as the flow rate slows near bottom dead centre (BDC). It increases again during the compression stroke as swirl, squish and tumble increase near top dead centre (TDC) [1]. Intake generated swirl usually persists through the compression, combustion, and expansion stroke and it can greatly enhances the mixing of air and fuel to give a homogeneous mixture in the very short time. It is also a main mechanism for very rapid spreading of the flame front during the combustion process [2]. Many researchers worked in this area via experimental as well as computational to explorer the phenomenon of the incylinder flow of Internal Combustion Engine. Some of them are cited here. B. Reveille and A. Duparchy [3] worked on 3D CFD analysis of an abnormally rapid Combustion phenomenon in downsized gasoline engines. This paper has focused on a particular abnormally rapid, yet non destructive and seemingly stable combustion phenomena which have been identified on low speed mid to high load operating points when performing aggressive downsizings on various engines. Franz X. Tanner & Seshasai Srinivasan [4] worked on CFD-based optimization of fuel injection strategies in a diesel engine using an adaptive gradient method. A gradient-based optimization tool has been developed and, in conjunction with a CFD code, utilized in the search of new optimal fuel injection strategies. The approach taken uses a steepest descent method with an adaptive cost function, where the line search is performed with a backtracking algorithm. Vijaya Kumar Cheeda, R. Vinod Kumar, G. Nagarajan [5] worked on design and CFD analysis of a regenerator for a turboshaft helicopter engine. In this paper a continuous heat transfer regenerator for a turboshaft helicopter engine is designed suitably. The regenerator effectiveness is assessed by the CFD tool CFX and evaluated the effectiveness and the pressure drop. The predicted CFD results are in good agreement with experimental results. L. Li, X.F. Peng, and T. Liu [6] worked on combustion and cooling performance in an aero-engine annular combustor. The investigation was conducted to understand the characteristics of the flow, combustion, cooling performance and their interaction in an aero-engine combustor. The conservation equations and Eddy-dissipation combustion model were employed

1 INTRODUCTION

47 for solving the flow, heat transfer, and combustion in the entire combustor. The reliability of the simulation
48 was demonstrated by comparing calculated combustor exit temperature distributions with profiles of the rig-
49 test measurements. Christian Hasse, Volker Sohm, and Bodo Durst [7] worked on Numerical investigation of
50 cyclic variations in gasoline engines using a hybrid URANS/LES modeling approach. The study investigates the
51 feasibility of using the SST DES model to predict cycle to cycle variations in internal combustion engines and the
52 effect of cyclic variations in engines and their root causes including the major flow patterns. Wendy Hardyono
53 Kumiawan, Shahrir Abdullah and Azhari Shamsudeen [8] worked on CFD study of cold-flow analysis for mixture
54 preparation in a motored four-stroke direct injection engine. In this study, the CFD simulation to investigate
55 the effect of piston crown to the fluid flow field inside the combustion chamber of a four-stroke direct injection
56 automobile engine under the motoring condition is presented. The analysis is focused on study of the effect of the
57 piston shape to the fluid flow characteristics the result obtained from the analysis could be employed to examine
58 the homogeneity of airfuel mixture structure for better combustion process and engine performance. Andras
59 Kadocsa, Reinhard Tatschl and Gergely Kristof [9] worked on analysis of spray evolution in internal combustion
60 engines using numerical simulation. This paper summarizes results of research about a new approach of spray
61 formation calculations. Using a primary breakup model for separately describing the initial liquid disintegration
62 of injected liquid based on the flow properties stemming from a previous calculation of injector nozzle flow gives
63 a better prediction capability and suits the new needs of advanced combustion systems such as HCCI engines or
64 various forms of split injection. Toyoshige Shibata Hideo Matsui, Masao Tsubouchi and Minoru Katsurada [10]
65 worked on Evaluation of CFD Tools Applied to Engine Coolant Flow Analysis. This paper presents the results of
66 test application of some automatic mesh generation tools to the CFD calculation of coolant flow, and compares
67 the functional characteristics and features of these tools. The paper also discusses coolant flow items that can
68 be evaluated by CFD analysis and the merits of applying CFD to these items. Semin, N.M.I.N. Ibrahim, Rosli
69 A. Bakar and Abdul R. Ismail [11] worked on In-Cylinder Flow through Piston-Port Engines Modeling using
70 Dynamic Mesh. This paper presents numerical study of three-dimensional analysis of two-stroke spark-ignition
71 cross loop-scavenged port. The objective of this study is to investigate the incylinder characteristics at motored
72 transient condition. The pressure on in-cylinder and intake port were collected and applied for validation with
73 numerical results for 1400 rpm. The three-dimensional modeling analysis was performed utilizing dynamic mesh
74 method. The prediction of distribution of in-cylinder pressure and mass fraction of gases function of crank angle
75 were discussed. The results shown that the relative error between experimental and numerical less than 2 %.
76 Helmut Doleisch [12] worked on simvis: interactive visual analysis of large and time-dependent 3d simulation
77 data. In this paper the major new technological concepts of the SimVis approach are presented and real-world
78 application examples are given. SimVis is a system for the graphical analysis of simulation data, built on a
79 new, cutting-edge technological approach for interactive visual analysis of large, multi-dimensional, and time-
80 dependent data sets resulting from CFD simulation. S. M. Jameel Basha, P. Issac Prasad and K. Rajagopal [13]
81 worked on simulation of in-cylinder processes in a DI diesel engine with various injection timings. In this paper
82 an attempt has been made to study the combustion processes in a compression ignition engine and simulation was
83 done using computational fluid dynamic (CFD) code Fluent. An Axisymmetric turbulent combustion flow with
84 heat transfer is to be modeled for a flat piston 4-stroke diesel engine. The unsteady compressible conservation
85 equations for mass (Continuity), axial and radial momentum, energy, species concentration equations can express
86 the flow field and combustion in axisymmetric engine cylinder. Turbulent flow modeling and combustion modeling
87 was analyzed in formulating and developing a model for combustion process. R. Rezaei, S. Pischinger, P. Adomeit
88 and J. Ewald [14] worked on Evaluation of CI In-Cylinder Flow using optical and numerical techniques. In this
89 paper different port concepts for modern Compression-Ignition engines, usually quantities as the swirl level and
90 the flow coefficient are evaluated, which are measured on a stationary flow test bench. As additional criterion,
91 in this work, the homogeneity of the swirl flow is introduced and defined quantitatively. Different valve lift
92 strategies are evaluated using three-dimensional Particle Imaging Velocimetry in a stationary flow configuration
93 and transient In-Cylinder CFD simulation using both the Reynolds Averaged Navier Stokes equation and the
94 Large Eddy simulation approach. M.M.Noor1, K.Kadirgama1, R.Devarajan, M.R.M.Rejab, N.M.Zuki N.M. and
95 T.F.Yusaf [15] worked on Development of a High Pressure Compressed Natural Gas Mixer for A 1.5 Litre CNG-
96 Diesel Dual Engine. In this paper Computational Fluid Dynamics (CFD) analysis software was used to study the
97 flow behavior of compressed natural gas (CNG) and air in a CNG-air mixer to be introduced through the air inlet
98 of a CNG-Diesel dual fuel stationary engine. Yasar Deger, Burkhard Simperl and Luis P. Jimenez [16] worked
99 on Coupled CFD-FE-Analysis for the Exhaust Manifold of a Diesel Engine. This paper aims to investigate the
100 thermo-mechanical behaviour of an exhaust manifold which has an active cooling system, the full water flow,
101 partial water flow (by 50% reduced cooling flow) and Vapour flow three cases of cooling analyzed. Fluid flow,
102 thermal heat transfer and stress analysis are coupled for each case using a oneway coupling approach. Selected
103 results given in form of temperature, stress and displacement distribution plots in this paper. The investigation
104 was focusing on potential structural optimization measures. Therefore some suggestions for design improvements
105 are presented also, which are presumably effective to reduce the temperature peaks and temperature gradients
106 and to ensure a longer service life for the exhaust manifold. Kihyung Lee, Choongsik Bae, and Kernyong Kang
107 [17] worked on the effects of tumble and swirl flows on flame propagation in a four-valve S.I. engine. The effects
108 of in-cylinder flow patterns, such as tumble and swirl flows, on combustion were experimentally investigated
109 in a four valve S.I. engine. Tumble flows were generated by intake ports with entry angles of 25°, 20°

110 and 15 ? . Inclined tumble (swirl) flows were induced by two different swirl control valves. The initial flame
111 propagation was visualized by an ICCD camera, the images of which were analyzed to compare the enflamed
112 area and the displacement of initial flames. The combustion duration was also calculated by the heat release
113 analysis. B. Murali Krishna and J. M. Mallikarjuna [18] worked on Tumble flow analysis in an unfired engine
114 using particle image velocimetry. This paper deals with the experimental investigations of the in-cylinder tumble
115 flows in an unfired internal combustion engine with a flat piston at the engine speeds ranging from 400 to 1000
116 rev/min., and also with the dome and dome-cavity pistons at an engine speed of 1000 rev/min., using particle
117 image velocimetry and It is suggested in the paper to use the flat piston rather than dome, dome-cavity pistons
118 which are rather difficult to manufacture as far as tumble flows are concerned. B. Khalighi worked on Study
119 of the intake tumble motion by flow visualization and PTV [19].The purpose of this work is to characterize the
120 in-cylinder tumbling flow generated by an engine head during the induction process using flow visualization and
121 PTV. The study was carried out for a 4-valve engine head with shrouded intake valves in special single cylinder
122 transient water analog. This shrouded intake valve configuration was used to obtain a prototypical "pure tumble"
123 flow suitable for fundamental combustion studies. K.M Pandey, S.N Pandey, and Bidesh Roy [20] worked on
124 numerical analysis to determine the effect of temperature on the intake generated swirl for port fuel injection
125 SI engine. Hence, for computational investigation for intake swirl within the engine, cold flow simulation will
126 provide faster computational result. In this study it was concluded that the temperature on various part of the
127 engine produces a very negligible effect on the intake swirl generation. Thus, we can see that very few works
128 have been done in field of determining the behavior of intake swirl red along the length of the engine cylinder.

129 2 II.

130 3 Specification of the Si Engine

131 The engine considered for the computation analysis is a single-cylinder continuous type port fuel injection four
132 stroke SI engine with cylindrical combustion chamber and single intake port and exhaust port. The computation
133 analysis is performed at WOT maximum power condition. The specification of engine is listed in Table 1.

134 4 Poppet Intake Valve

135 A Poppet intake valve is used in the SI engine in which the computational analysis is performed

136 5 Computational Domain and Boundary Conditions

137 The numerical formulation of the problem is incomplete without prescribing boundary conditions, which
138 correspond to the specific physical model. The specification of mathematically correct boundary conditions that
139 ensure the uniqueness of the solution, while being compatible with the physics at the boundaries, is not always
140 straightforward. Before arriving at the boundary conditions at various boundaries, we have to first identify the
141 solution/computational domain of the problem. The physical domain and computational domain usually differ.
142 However, the computational domain largely depends on the geometry of physical domain. The computational
143 domain boundary (truncated from the real boundary) along with appropriate boundary conditions should be
144 chosen in such a way that there is negligible change in the results with further increase in its size.

145 The computational domain shown in the figure 2 is a generalized one since, the analysis is performed at
146 different crank angle during the suction stroke of the engine as result the distance of the piston from the engine
147 head shown in the figure 2 by "B" also varies corresponding to the engine crank angle. The inlet boundary
148 condition is assigned as mass flow inlet. Since the investigation is performed at 72 degree of the crank angle and
149 at that instant the mass flow inlet of air is 0.01319 kg/sec for the computation.

150 II. Solid surface of the cylinder of the engine: -It is assigned wall boundary condition i.e. no slip condition on
151 the solid surface of the cylinder. The computation is performed with solid surface of the cylinder at a temperature
152 of 300 ? K for faster computational result [20].

153 III. Outlet Boundary on the piston of the engine: -Outlet boundary is assigned the pressure outlet boundary
154 condition. For the investigation outlet pressure is taken as a static pressure of 0:935 bar.

155 IV. Discrete phase surface injection for injector: -In the computation domain the injector of the valve is assign
156 as discrete phase surface injection with fuel flow rate of 0.0011 kg/sec for the engine considered.

157 V.

158 6 Grid Independence Study

159 The resolution of the grid has a great quantitative impact over the results obtained. There exists a level of refining
160 of a computational domain beyond which there is no significant quantitative changes in the results achieved. The
161 computational domain at this level of refinement is said to enter the regime of grid independence. In the present
162 work maximum tangential velocity at a surface 9.18mm from engine cylinder head has been taken as the criteria
163 and the number of grid is refined until the required value is gained. For the simulation grid independence was

7 Result and Discussion

164
165 Computational result at 72 ° crank angle for the specified SI engine at various locations along the length of the
166 engine cylinder is shown below:- From the equation 1, it is clear that tangential velocity plays a vital role in
167 determining the intensity of swirl within the engine.

168 From the results of the computation analysis carried out at 72 ° crank angle with poppet intake valve, for the
169 specified SI engine it is seen that the surface at 9.18mm from engine cylinder head which is closer to the valve
170 shows higher tangential velocity at various location compared to the surface at 18.1mm and 28.8mm from engine
171 cylinder head which is at higher distance from the intake valve.

8 VII.

9 Conclusion

172
173
174 From this study the following it can be concluded that the surface which is closer to the poppet intake valve
175 shows higher tangential velocity at various locations compared to the surfaces which are at higher distance from
the intake valve i.e. the intensity of swirl decreases along the stroke length of the engine cylinder.



Figure 1:

176

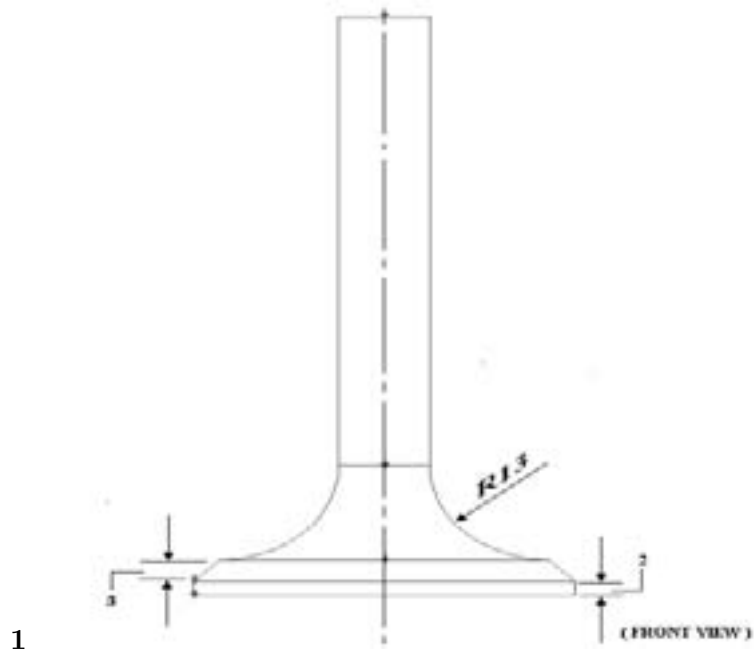


Figure 2: Figure 1 :

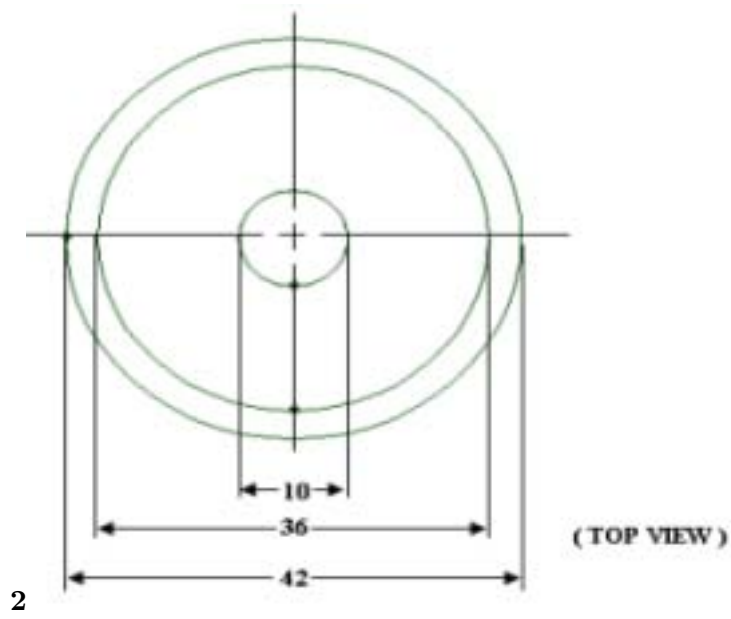
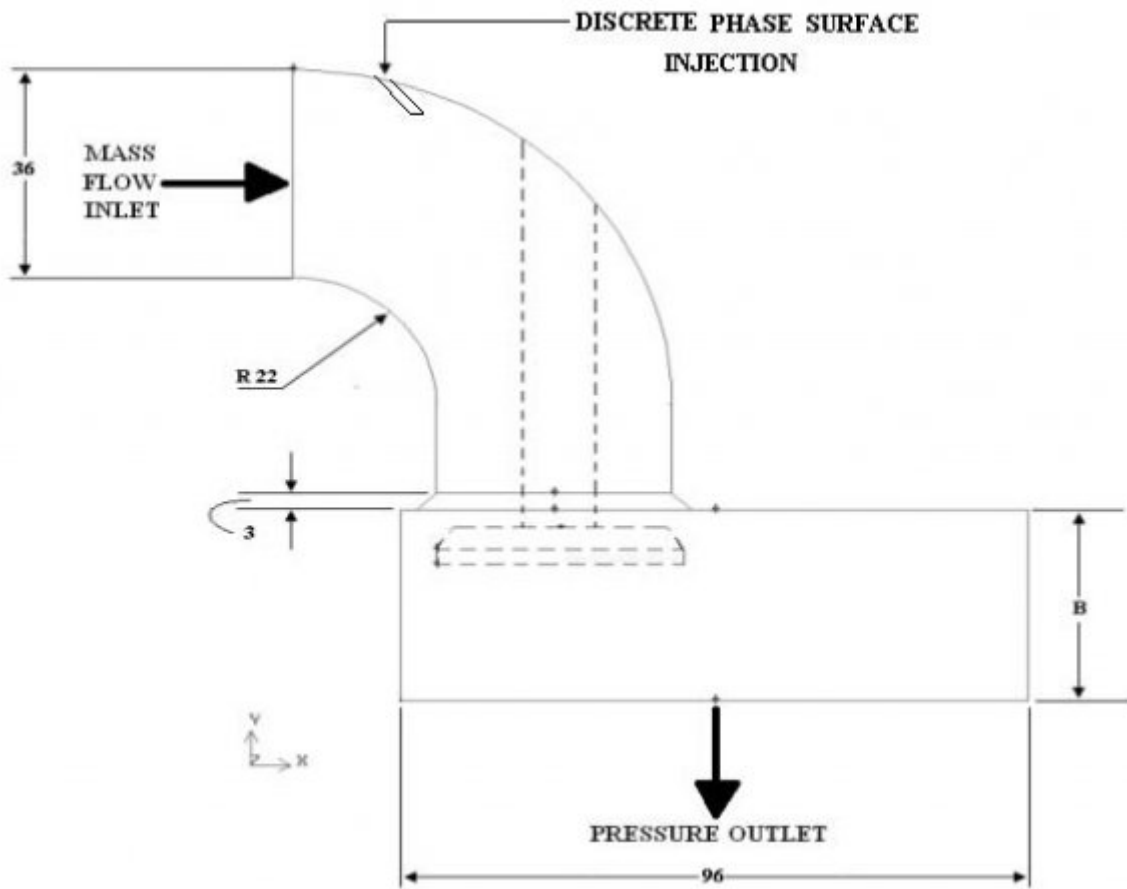


Figure 3: Figure 2 :



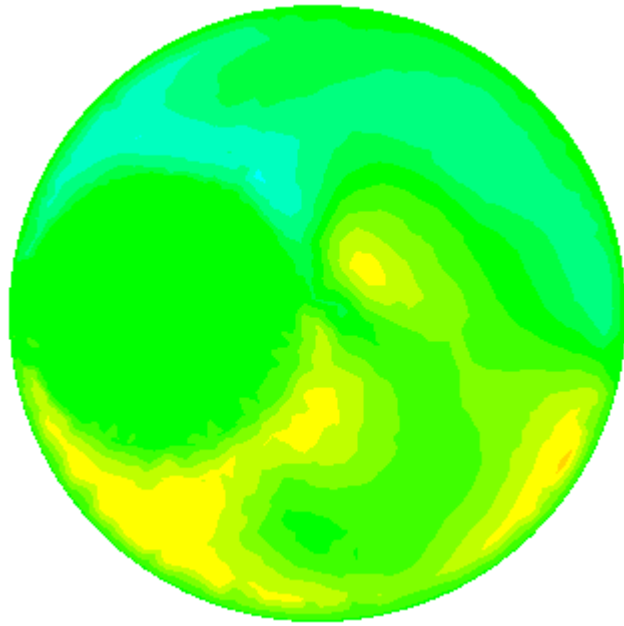
3

Figure 4: Figure 3 :



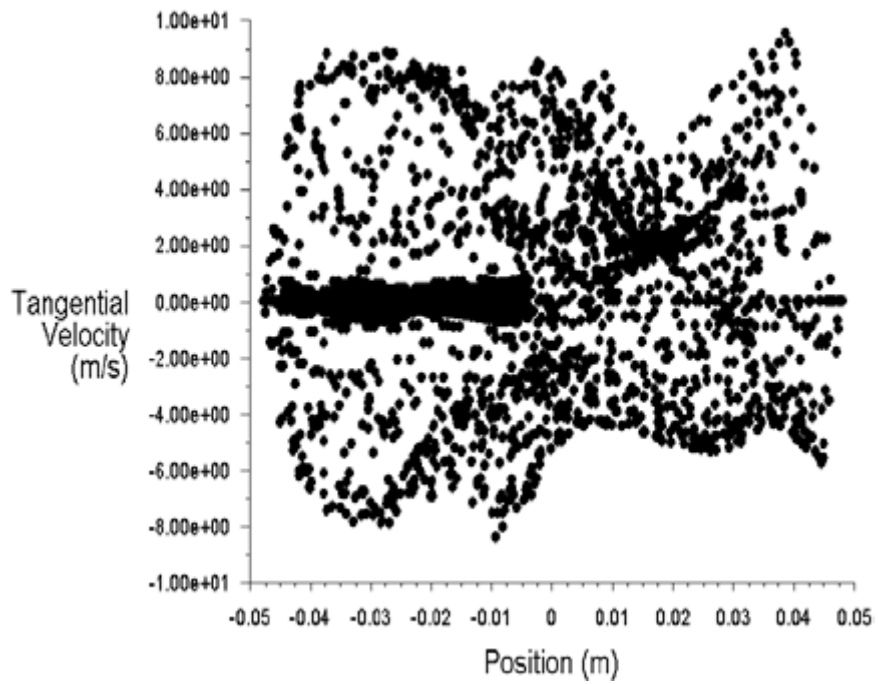
4

Figure 5: Figure 4 :



5

Figure 6: Figure 5 :



6

Figure 7: Figure 6 :

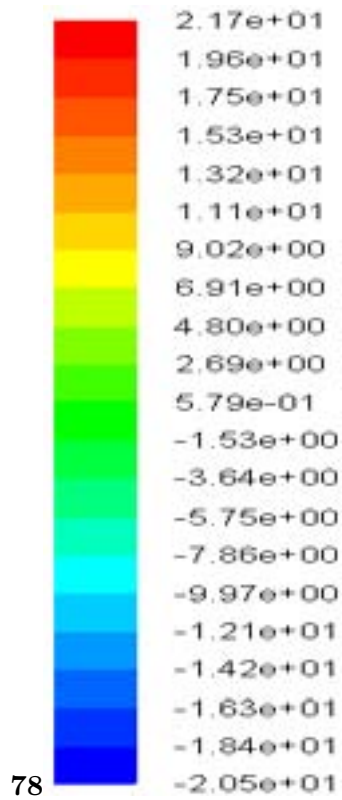


Figure 8: Figure 7 :Figure 8 :

1

calculation conditions	
Bore x stroke	95mm x 99mm.
Compression ratio	9:1
Piston cavity	Flat.
Max power at WOT	13.2 BHP at 4950 RPM.
Intake valve diameter	42mm
Maximum intake valve lift	12mm.
Exhaust valve opening	64 ? BBDC.
Exhaust valve closure	5 ? ATDC.
Intake valve opening	5 ? BTDC.
Intake valve closure	60 ? ABDC.
Fuel	C 8 h 18
III.	

Figure 9: Table 1 :

2

Refining Level	No. of Nodes	No. of cells	Max. Tangential velocity at a surface 9.18mm from engine cylinder head
1)	53307	254668	10 m/sec
2)	52208	244537	10 m/sec
3)	82377	384876	8.8 m/sec
VI.			

Figure 10: Table 2 :

-
- 177 [Kurniawan] , W H Kurniawan .
- 178 [Reveille and Duparchy ()] ‘3D CFD analysis of an abnormally rapid Combustion phenomenon in downsized
179 gasoline engines’. B Reveille , A Duparchy . *Oil & Gas Science and Technology -Rev. IFP* 2009. 64 (3) p. .
- 180 [Kadocsa et al. ()] ‘Analysis of spray evolution in internal combustion engines using numerical simulation’.
181 Andras Kadocsa , Reinhard Tatschl , Gergely Kristof . *Journal of Computational and Applied Mechanics*
182 2007. 8 (1) p. .
- 183 [Hardyono Kumiawan et al.] *CFD study of cold-flow analysis for mixture preparation in a motored four*, Wendy
184 Hardyono Kumiawan , Shahrir Abdullah , Azhari Shamsudeen .
- 185 [Franz et al. ()] ‘CFD-based optimization of fuel injection strategies in a diesel engine using an adaptive gradient
186 method’. X Franz , Tanner & Seshasai , Srinivasan . *Applied Mathematical Modelling* 2009. 33 p. .
- 187 [Li et al. ()] ‘Combustion and cooling performance in an aero-engine annular combustor’. L Li , X F Peng , T
188 Liu . *Applied Thermal Engineering* 2006. 26 p. .
- 189 [Deger et al. ()] ‘Coupled CFD-FE-Analysis for the Exhaust Manifold of a Diesel Engine’. Yasar Deger , Burkhard
190 Simperl , Luis P Jimenez . *ABAQUS Users’ Conference*, 2004. p. .
- 191 [Vijaya Kumar Cheeda et al. ()] ‘Design and CFD analysis of a regenerator for a turbo shaft helicopter engine’.
192 R Vinod Vijaya Kumar Cheeda , G Kumar , Nagarajan . *Aerospace Science and Technology* 2008. 12 p. .
- 193 [Devarajan et al. ()] ‘Development of a High Pressure Compressed Natural Gas Mixer for A 1.5 Litre CNG-Diesel
194 Dual Engine’. R Devarajan , M R M Rejab , N M Zuki , NM , T F Yusaf . *National Conference on Design
195 and Concurrent Engineering* 2009. p. .
- 196 [Shibata Hideo Matsui et al. ()] *Evaluation of CFD Tools Applied to Engine Coolant Flow Analysis, Mitsubishi
197 motors technical review*, Toyoshige Shibata Hideo Matsui , Masao Tsubouchi , Minoru Katsurada . 2004. p. .
- 198 [Semin et al. ()] ‘In-Cylinder Flow through Piston-Port Engines Modeling using Dynamic Mesh’. N M I N Semin
199 , Ibrahim , A Rosli , Abdul R Bakar , Ismail . *Journal of Applied Sciences Research* 2008. 4 (1) p. .
- 200 [Heywood ()] *Internal combustion engine fundamental*, J Heywood . 1988. New York: McGraw-Hill.
- 201 [Pandey et al. ()] ‘Numerical analysis to determine the effect of temperature on the intake generated swirl for
202 port fuel injection SI engine’. K Pandey , S Pandey , Bidesh Roy . *proceeding of National conference on
203 Emerging trends in mechanical engineering (ETME-2010)*, (eeding of National conference on Emerging trends
204 in mechanical engineering (ETME-2010)) May 14-15,2010.
- 205 [Hasse et al. ()] ‘Numerical investigation of cyclic variations in gasoline engines using a hybrid URANS/LES
206 modeling approach’. Christian Hasse , Volker Sohm , Bodo Durst . *Computers & Fluids* 2009. (article in
207 press, Contents lists available at Science Direct)
- 208 [Rezaei et al. (2009)] R Rezaei , S Pischinger , P Adomeit , J Ewald . *Evaluation of CI In-Cylinder Flow using
209 optical and numerical techniques, SAE ICE conference*, September 2009.
- 210 [Basha and Prasad (2009)] ‘Simulation of in-cylinder processes in a DI diesel engine with various injection
211 timings’. S M Basha , P Prasad , K . *ARPJ journal of engineering and applied sciences* February 2009.
212 4 (1) p. .
- 213 [Doleisch] ‘SIMVIS: Interactive visual analysis of large and time-dependent 3D simulation data’. Helmut Doleisch
214 . *Proceedings of the 2007 Winter Simulation Conference*, (the 2007 Winter Simulation Conference) p. .
- 215 [Khalighi ()] ‘Study of the intake tumble motion by flow visualization and particle tracking velocimetry’. B
216 Khalighi . *Experiments in Fluids* 1991. 10 p. .
- 217 [Lee et al. ()] ‘The effects of tumble and swirl flows on flame propagation in a four-valve S.I. engine’. Kihyung
218 Lee , Choongsik Bae , Kernyong Kang . *Applied Thermal Engineering* 2007. 27 p. .
- 219 [Krishna and Mallikarjuna ()] ‘Tumble flow analysis in an unfired engine using particle image velocimetry’. B
220 Krishna , J M Mallikarjuna . *World Academy of Science, Engineering and Technology* 2009. 54 p. .
- 221 [Abdullah and Shamsudeen ()] ‘Turbulence and Heat Transfer Analysis of Intake and Compression Stroke in
222 Automotive 4-stroke Direct Injection Engine’. S Abdullah , A Shamsudeen . *Algerian Journal of Applied
223 Fluid Mechanics* / 2007. 1 p. .