CFD Analysis of Fuel Injection System using ANSYS CFX

Ankit Kumar Tiwari[1], Purushottam Kumar Sahu[2]

[1]Research Scholar BM College of Technology, Indore RGPV Bhopal
[2]Professor BM College of Technology, Indore RGPV Bhopal

---***---

Abstract - *In the current study, fuel injection engine CFD analysis is performed to determine the design parameters produced by thrust force and static enthalpy. The design parameters are related to the number of fuel inlets, i.e. (1, 3 and 5). The quantity of fuel intake has a significant effect on combustion, which in turn affects the enthalpy output and thus the thrust strength. The Eddy dissipation combustion model used for CFD analysis provides a better approximation of fluid flows compared to other techniques. The pressure plot of all designs shows the highest pressure value in the combustion zone for all design configurations (1, 3 and 5 inlets). The pressure decreases along the length of the fuel injection engine tube and along the length of the fuel injection engine tube highest being in the combustion zone*

Key Words: Fuel Injector, Nozzle geometry, diesel fuel, Outlet velocity, Transient Fuel Spray Formation, optimization

1. INTRODUCTION

If the engine is considered to be the heart of the vehicle, then the heart of the diesel engine is the fuel injection equipment (FIE).The FIE pumps the diesel fuel to the engine that is required for it to operate. It also affects the engine's output and most of the engine characteristics are dependent on the FIE's performance. The FIE's value is such that much of the diesel engine's production has been closely related to the FIE's development over the years.

1.1 Diesel Engine

Dr. Rudolf Diesel developed the Diesel engine, also known as a compression-ignition engine, in an effort to improve the spark ignition engine's comparatively poor thermal efficiency by using a higher compression ratio. During the engine's compression stroke, the air in the combustion chamber is heated to such a degree that it self-ignites when the fuel is injected. During the initial engine development, injecting the fuel directly into the engine proved unsatisfactory, and so compressed air was used to force it into the combustion chamber. This air blast injection process, however, was slow and costly and was ultimately replaced by a mechanical device. The system that has been generally accepted was the 'jerk pump ‘system in which an injection pump meters the fuel and injects it at high pressure through small-hole injectors into the combustion chamber.

1.2Direct and Indirect Fuel Injection

Both diesel engines have fuel injection systems, unlike traditional petrol engines, also known as spark-ignition (SI) engines with carburettors. The method of injection falls into one of two types, namely Direct Injection (DI) or Indirect Injection (IDI). As the name indicates, direct injection applies, see Figure 1.1, to all systems in which fuel is directly injected into the combustion chamber. In a small pre-chamber or turbulence chamber in IDI engines, a relatively rich fuel mixture is first ignited, see Figure 1.2, and this burning mixture then passes into the main combustion chamber, where it mixes with the remaining compressed air and burns it very effectively. Traditionally, only IDI systems have been used in diesel passenger vehicles. This was due to relatively smooth combustion, lower operating noise and the fuel injection system's relatively low requirements to achieve successful high-speed fuel/air mixing. However, DI diesel engines consume 10-15% less fuel and, naturally, this has led to the development of car engines with direct fuel injection into a piston-bowl located eccentric to the piston axis.

1.1 Literature Review

In 2016, FuyingXue , FuqiangLuo, Huifeng Cui, Adams Moro, Liying Zhou[1] This article mentions the definition and model of mathematics relating to cavitation and turbulence. The turbulence flow pattern and cavitation evolution for nozzle holes of an asymmetric multi-hole diesel injector were reproduced using the multi-phase two fluid flow approaches, where the effect of injection conditions on the bubble number density was considered. The fuel flow characteristics of each nozzle cavity have been simulated, the fuel flow characteristics have been simulated and cavitation and turbulence effects have been analyzed. In cavitation, the evolution of holes has varied greatly. Nozzle angles and needle lifting mechanisms have been found to affect cavitation, mass movement and speed of flow.

In 2016, F.J. Salvador, D. Jaramillo, J.-V. Romero, M.-D.Rosello[2] In this paper, the behavior of the internal nozzle flow and cavitation phenomena was numerically analyzed for non-conventional Diesel convergent-divergent nozzles in order to determine their ability in terms of flow characteristics. The nozzles used vary from each other in the degree of convergence-divergence of the orifices, but they all maintain the same diameter at the center of the nozzle orifice. Using a biphasic fluid homogeneous equilibrium model and using a RANS technique, the calculations are performed using a code previously validated and ready to simulate a cavitation phenomenon. One injection pressure and various discharge pressures were used for the simulations in order to test nozzle characteristics for different Reynolds conditions involving cavitation.

In 2016, F.J. Salvador, J. De la Morena.Martínez-López. Jaramillo [3] An study of compressibility effects in nozzle flow simulations for injection pressures of up to 250 MPa was carried out in this paper. During a broad variety of boundary conditions, the fluid properties (including density, viscosity and speed of sound) are determined to do so. As a function of pressure and temperature, these measurements have allowed correlations to be obtained for the fluid properties. Then these equations are implemented into a CFD solver in order to take into account the variance of the fluid properties with pressure changes along the computational domain. Compared to experimental mass flow and outcomes of momentum flux

In 2016, V. Lazarev, G. Lomakin, E. Lazarev [4] The perfection of the diesel engine performance parameters is taken into account as a result of the increase in rail pressure and the modernization of the nozzle Tribo systems have a high (up to 300 MPa) fuel pressure value. The updated configuration nozzle and extra (bottom) precision guiding interface are used and hydrodynamic injection parameters are evaluated. Computational fluid-dynamic (CFD) modeling is used to estimate hydrodynamic fuel flow and force distribution parameters within the "needle-nozzle body" framework. The outcomes of the injection modeling are defined and the parameters for the changed design of nozzle precision interfaces are communicated. The ways of accelerating the steadiness of needle position within the nozzle body with perfection of parameters of fuel injection system are presented.

In 2016, Tao Qiu , Xin Song, Yan Lei, Hefei Dai , Chunlei Cao , HuiXu , Xiang Feng [5] This work explores the effects of the injection back pressure on the development of internal cavitation of the nozzle, especially the flow characteristic during the choking process. The following are the main observations: The cavitation process is split into 3 phases as the back pressure decreases. 1. During the time of choking, the rear pressure has little influence on the mass movement.

2. The discharge coefficient declines as the back pressure decreases during the choking period.

3. The interface between the liquid and the mixing section is constant throughout the choking time.

4. The outlet velocity increases during the choking time as the back pressure decreases.

In 2015, HengzhouWo , Karl D. Dearn , Ruhong Song , Enzhu Hu , YufuXu , Xianguo Hu [6] During a diesel process using an emulsion method, the blend of biomass oil and diesel was prepared and combusted. An injector was then extracted and a combination of HRTEM, SEM/EDAX, Raman and XRD represented the morphology, composition, and structure of the carbonaceous deposits on the pintle-type nozzle. The results revealed that the carbon deposition of the high crystalline emulsified fuel was greater than that of diesel. About 10-30 μm and 50 μm respectively were the agglomerated particulate diameters of the deposited carbon from diesel and emulsified gasoline. The process of emulsified fuel carbon deposition was due to the high oxygen content of the groups, resulting in increased polymerization and eventual condensation of the carbonized nozzle surfaces.

In 2013, Zhixia He, WenjunZhong, Qian Wang, Zhaochen Jiang, Zhuang Shao [7] A flow visualization experiment device with a transparent scaled-up multi-hole injector nozzle tip was set up and a strong agreement was finally shown between the two data sets in order to compare the measured results from the three-dimensional numerical cavitating flow simulation in the nozzle with a multi-phase cavitating flow model mixture to obtain the experimental data. In numerical simulations, as well as the relationship between the discharge coefficient and the non-dimensional cavitation parameter, the critical conditions for the beginning of cavitation were derived.

Subsequently, the tested numerical models were unable to examine the effects on the cavitating flow inside the nozzle of nozzle sac length, orifice inlet curvature, orifice inclination angle, injector needle elevation and needle eccentricity. The results of numerical simulation will clearly demonstrate the three-dimensional nature of the flow of the nozzle and the location and form of the vapor distribution caused by cavitation, which will help to better understand the flow of the nozzle and ultimately put forward the principles of optimization of diesel injectors.

In 2014, Sanghoon Lee , Sungwook Park [11] This paper analyzes, as a comparison, the spray features of a group-hole nozzle as opposed to the characteristics of a single-hole nozzle in terms of spray operation and atomization phase. Phase Doppler Particle Analyzers (PDPA) and spray visualization experiments have been performed using a customizable GDI injector that can adopt a particular nozzle shape under free spray conditions.g

Boundary conditions

The domain is defined as fluid. Reference pressure is set to 1atm. Two variable k-epsilon turbulence model is set for analysis and inlet pressure is set to 1400barand outlet pressure is set to 60Pa.The inlet boundary condition is defined with different mass fraction composition of gases and same for fuel inlet also.

Pressure Inlet – 1400 bar

2. Pressure Outlet – 60 bar

3. Temperature – 300K

4. Turbulence Kinetic Energy – 1 m^2/s^2

5. Turbulence Dissipation Rate – 1 m^2/s^3

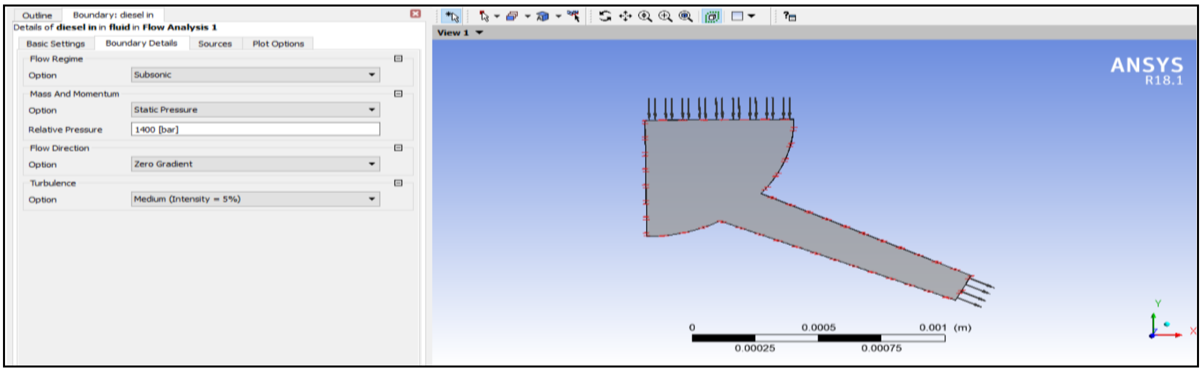

Figure 5.5 Inlet pressure on fuel injector

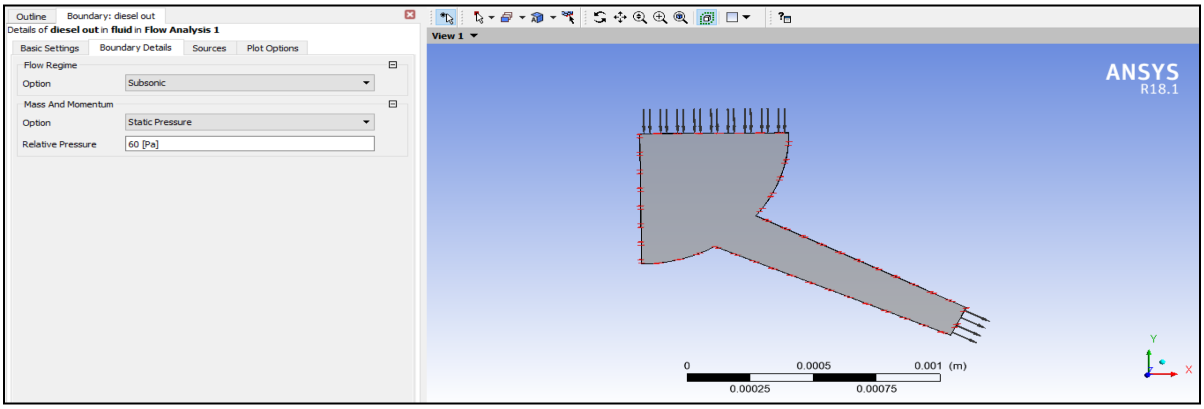

Figure 5.6 Outlet pressure on fuel injector

The 2 side surfaces are applied with symmetric boundary conditions as shown in figure 6.7 below. The symmetric boundary conditions simulate the condition on both sides.

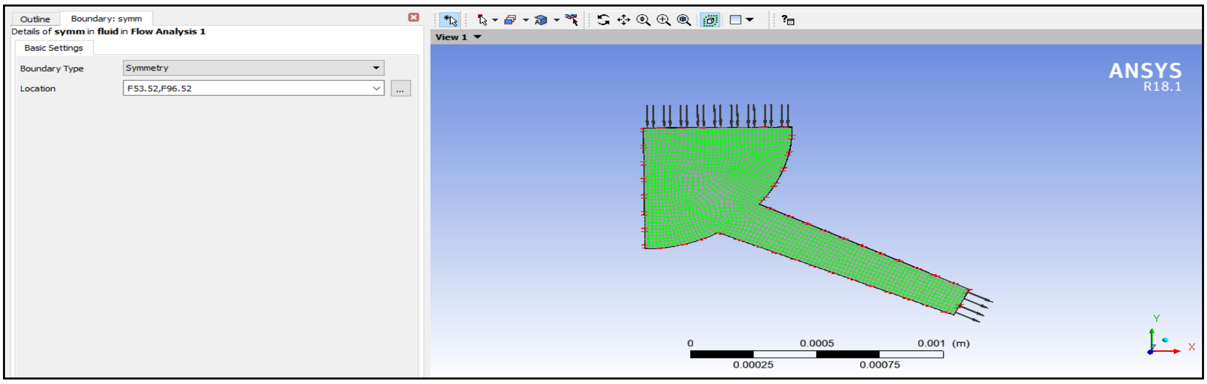

Figure 5.7 Symmetric boundary condition on fuel injector

Results and Discussion

The CFD analysis of fuel injector is conducted using ANSYS CFX to obtain pressure plot, velocity plot, eddy viscosity and turbulence kinetic energy for different values of D i.e.140, .150 and .169. The details are discussed in section below.

6.1 Diesel fuel with D=.140

The contour plot of pressure shows higher value at inlet as shown by red coloured zone with magnitude of $1.452*10^8$ Pa while tensile pressure is generated near outlet as shown in dark blue color with magnitude of $4.41*10^7$Pa.

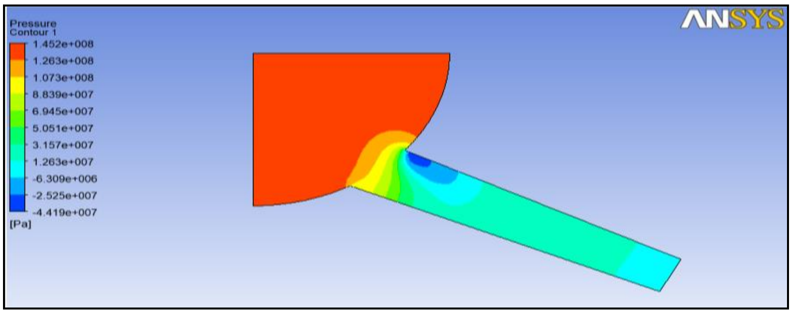

Figure 6.1: Pressure plot for diesel fuel with D=.140

The contour plot of velocity shows higher value at nozzle as shown by red coloured zone with magnitude of 602.3m/s and reduced velocity near walls of nozzle as shown in dark blue colour with magnitude of 1.642m/s.The outlet portion of nozzle has also higher velocity compared to rest of region.

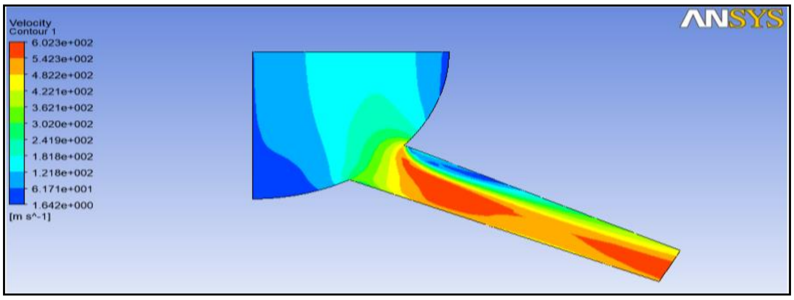

Figure 6.2: Velocity plot for diesel fuel with D=.140

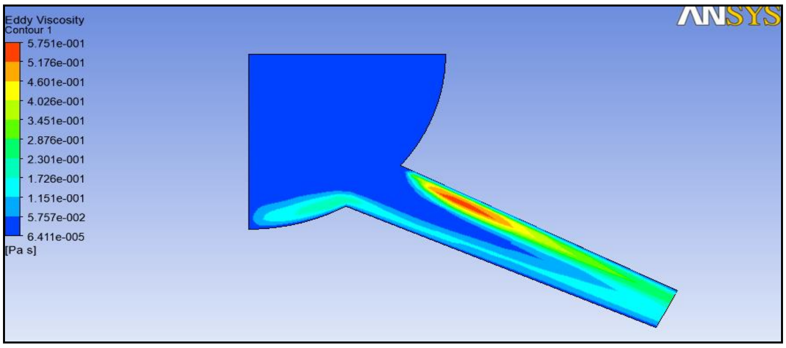

Figure 6.3: Eddy viscosity plot for diesel fuel with D=.140

The eddy viscosity plot for D=.140 shows higher magnitude near walls of nozzle towards exit as shown in red coloured zone with magnitude of .575 Pa S and decreases as we move away from wall as shown by light blue and dark blue coloured regions.

6.2 Diesel fuel with D=.150

The contour plot of pressure shows higher value at inlet as shown by red coloured zone with magnitude of $1.453*10^8$ Pa while tensile pressure is generated near outlet as shown in dark blue color with magnitude of $5.142*10^7$Pa.

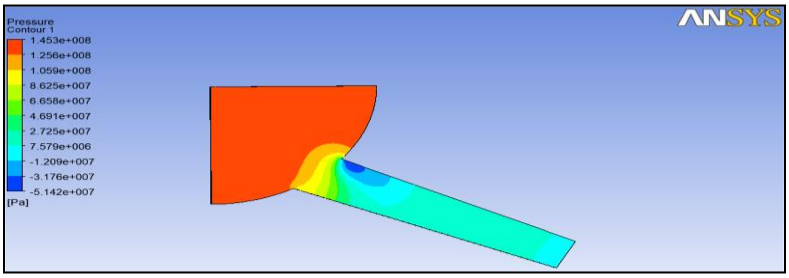

Figure 6.4: Pressure plot for diesel fuel with D=.150

The contour plot of velocity shows higher value at nozzle as shown by red coloured zone with magnitude of 620.4m/s and reduced velocity near walls of nozzle as shown in dark blue colour with magnitude of 1.888m/s. The outlet portion of nozzle has also higher velocity compared to rest of region.

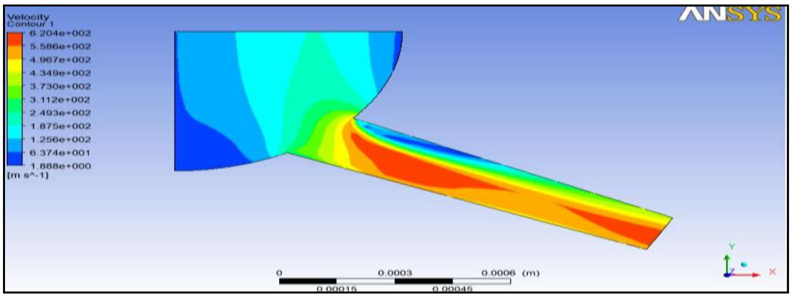

Figure 6.5: Velocity plot for diesel fuel with D=.150

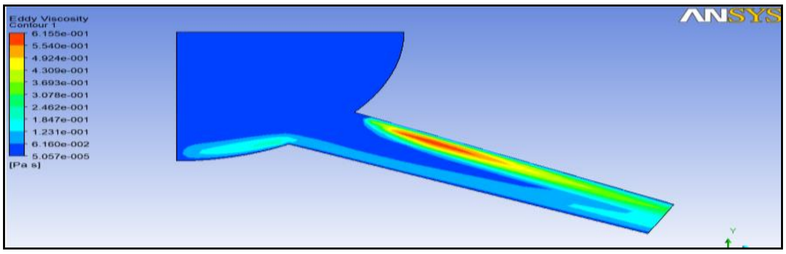

Figure 6.6: Eddy viscosity plot for diesel fuel with D=.150

The eddy viscosity plot for D=.150 shows higher magnitude near walls of nozzle towards exit as shown in red coloured zone with magnitude of .615 Pa S and decreases as we move away from wall as shown by light blue and dark blue coloured regions.

6.3 Diesel fuel with D=.169

The contour plot of pressure shows higher value at inlet as shown by red coloured zone with magnitude of $1.413*10^8$ Pa while tensile pressure is generated near outlet as shown in dark blue color with magnitude of $7.353*10^7$Pa.

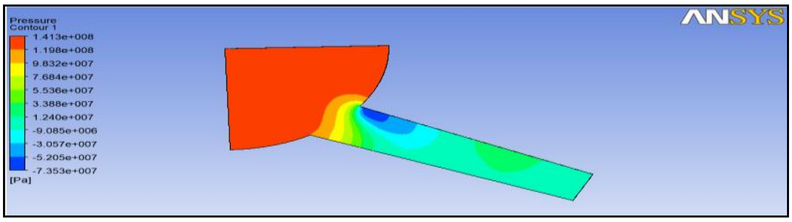

Figure 6.7: Pressure plot for diesel fuel with D=.169

The contour plot of velocity shows higher value at nozzle as shown by red coloured zone with magnitude of 686.7m/s and reduced velocity near walls of nozzle as shown in dark blue colour with magnitude of .715m/s. The outlet portion of nozzle has also higher velocity compared to rest of region.

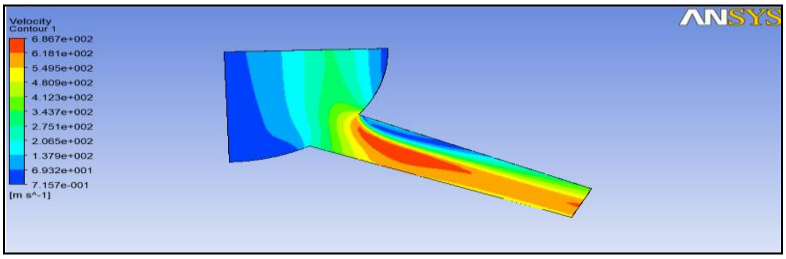

Figure 6.8: Velocity plot for diesel fuel with D=.169

The eddy viscosity plot for D=.169 shows higher magnitude near walls of nozzle towards exit as shown in red coloured zone with magnitude of .8486 Pa S and decreases as we move away from wall as shown by light blue and dark blue coloured regions.

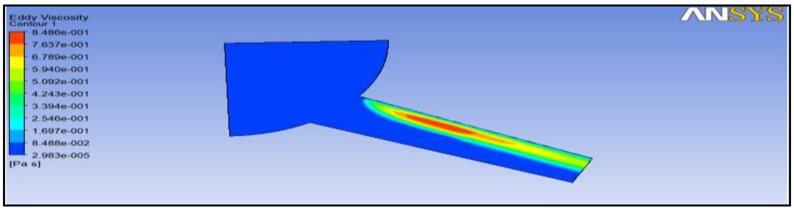

Figure 6.9: Eddy viscosity plot for diesel fuel with D=.169

Table 6.1: Outlet Velocity table

FUEL	D=.169	D=.150	D=.140
DIESEL	526.41	528.07	527.62
DME	591.56	590.625	587.73

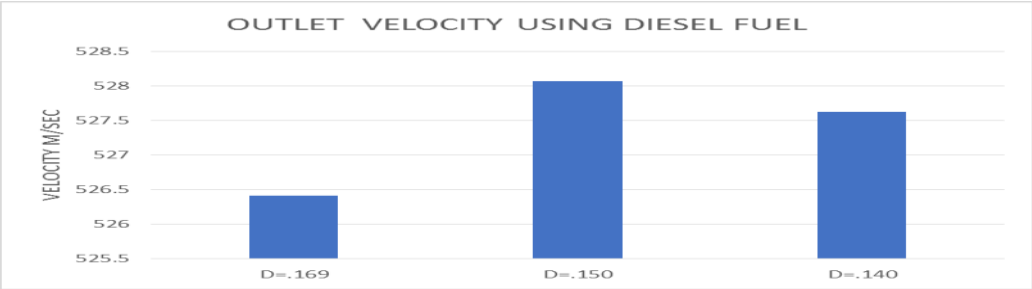

Figure 6.10: Outlet velocity comparison using diesel fuel

From outlet velocity comparison chart obtained for diesel fuel it is evident that maximum velocity of diesel fuel is observed for D=.150 followed by D=.140 and minimum for D=.169.

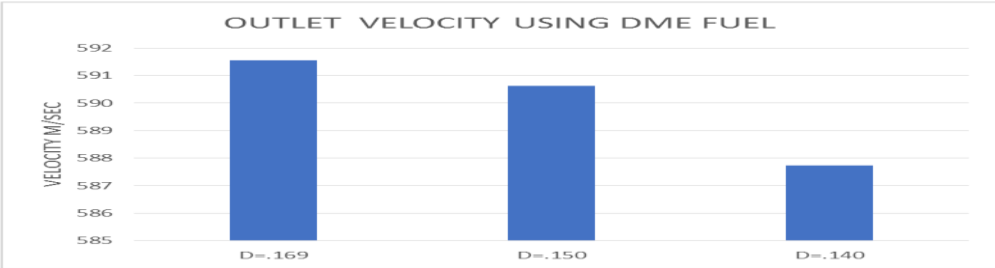

Figure 6.11: Outlet velocity comparison using DME fuel

From outlet velocity comparison chart obtained for DME fuel it is evident that maximum velocity of DME fuel is observed for D=.169 followed by D=.150 and minimum for D=.140.

Table 6.2: Outlet pressure

FUEL	**D=.169**	**D=.150**	**D=.140**
DIESEL	55281.1	47946.3	54607.7
DME	44675.2	47262.7	63999.9

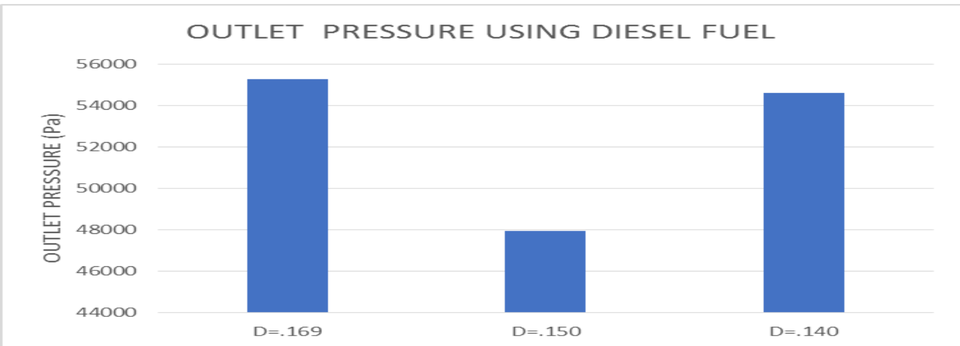

Figure 6.12: Outlet pressure comparison using diesel fuel

From outlet pressure comparison chart obtained for diesel fuel it is evident that maximum pressure of diesel fuel is observed for D=.169 followed by D=.140 and minimum for D=.150.

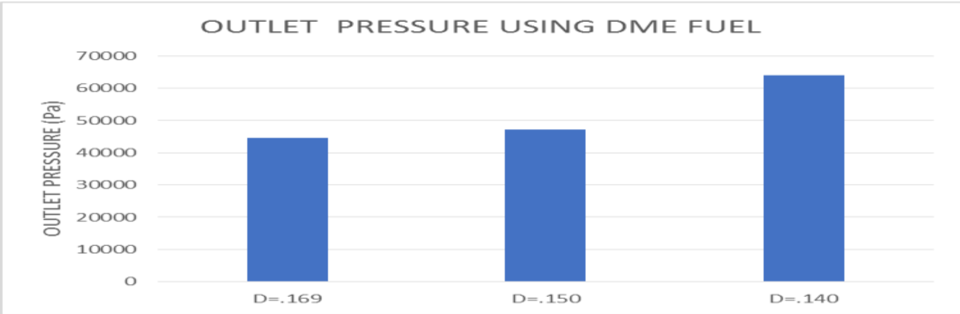

Figure 6.13: Outlet pressure comparison using DME fuel

From outlet pressure comparison chart obtained for diesel fuel it is evident that maximum pressure of DME fuel is observed for D=.140 followed by D=.150 and minimum for D=.169.

Conclusions

In the current research CFD analysis of fuel injection engine is conducted to determine the design parameters on thrust force and static enthalpy generated. The design parameters are related to number of fuel inlets i.e. (1, 3 and 5). The number of fuel inlet has significant effect on combustion which in turn effects enthalpy and thus thrust force generation. The detailed conclusions are:

i. The combustion model of eddy dissipation used for CFD analysis offers improved prediction of fluid flows compared to other models.
ii. For all system configurations, the pressure graph of all designs indicates the highest pressure value in the combustion zone (1, 3 and 5 inlet)
iii. The pressure decreases over the length of the fuel injection engine tube and is highest in the combustion zone.
iv. Compared to the single fuel inlet configuration, a strong quantum of improvement is found in the generation of thrust force using multiple fuel inlet configurations.
v. Compared to 3 inlet and 1 inlet configurations, the fuel injection system with 5 fuel inlet designs has the maximum thrust provided.
vi. The produced static enthalpy is highest in the configuration of 5 fuel inlets and lowest in the configuration of single fuel inlets.
vii. Five fuel inlet configurations with a magnitude of 23763 kN are used for the highest thrust produced.
viii. The single fuel inlet configuration with a magnitude of 8876kN is the lowest thrust produced.

References:

[1] FuyingXue , FuqiangLuo, Huifeng Cui, Adams Moro, Liying Zhou, "Numerical analyses of transient flow characteristics within each nozzle hole of an asymmetric diesel injector", International Journal of Heat and Mass Transfer 104 (2017) 18–27

[2] F.J. Salvador, D. Jaramillo, J.-V.Romero, M.-D.Rosello, "Using a homogeneous equilibrium model for the study of the inner nozzle flow and cavitation pattern in convergent–divergent nozzles of diesel injectors s", Journal of Computational and Applied Mathematics

[3] F.J. Salvador, J. De la Morena .Martínez-López. Jaramillo, "Assessment of compressibility effects on internal nozzle flow in diesel injectors at very high injection pressures" , Energy Conversion and Management 132 (2017) 221–230

[4] V. Lazarev, G. Lomakin, E. Lazarev, "Modeling of Injection Parameters for Diesel Engine Injector Nozzles with the Additional Precision Guiding Interface", Procedia Engineering 150 (2016) 52 – 60

[5] Tao Qiu , Xin Song, Yan Lei, Hefei Dai , Chunlei Cao , HuiXu , Xiang Feng, "Effect of back pressure on nozzle inner flow in fuel injector", Fuel 173 (2016) 79–89

[6] HengzhouWo , Karl D. Dearn , Ruhong Song , Enzhu Hu , YufuXu , Xianguo Hu, "Morphology, composition, and structure of carbon deposits from diesel and biomass oil/diesel blends on a pintle-type fuel injector nozzle", TribologyInternational91(2015)189–196

[7] Zhixia He, WenjunZhong, Qian Wang, Zhaochen Jiang, Zhuang Shao, "Effect of nozzle geometrical and dynamic factors on cavitating and turbulent flow in a diesel multi-hole injector nozzle", International Journal of Thermal Sciences 70 (2013) 132e143

[8] Tong Haoa, Li Yonga, Zhang Longa, Li Baoquanb , "Mechanism design and process control of micro EDM for drilling spray holes of diesel injector nozzles", Precision Engineering 37 (2013) 213– 221

[9] Zhixia He , Zhengyang Zhang, GenmiaoGuo , Qian Wang , XianyingLeng , Shenxin Sun, "Visual experiment of transient cavitating flow characteristics in the real-size diesel injector nozzle ", International Communications in Heat and Mass Transfer 78 (2016) 13–20

[10] SiminAnvari , HadiTaghavifar, ShahramKhalilarya , SamadJafarmadar , Mohammad TaghiShervani-Tabar, "Numerical simulation of diesel injector nozzle flow and in-cylinder spray evolution", Applied Mathematical Modelling 0 0 0 (2016) 1–13

[11] SanghoonLee ,Sungwook Park, "Spray atomization characteristics of a GDI injector equipped with a group-hole nozzle", Fuel 137 (2014) 50–59

[12] Bo Wang, TawfikBadawy, Yizhou Jiang , HongmingXu, Akbar Ghafourian , Xinyu Zhang, "Investigation of deposit effect on multi-hole injector spray characteristics and air/fuel mixing process", Fuel 191 (2017) 10–24

[13] Yangbo Deng, HongweiWu, Fengmin Su, "Combustion and exhaust emission characteristics of low swirl injector", Applied Thermal Engineering 110 (2017) 171–180

[14] F.J. Salvador , J. Martínez-López , M. Caballer, C. De Alfonso, "Study of the influence of the needle lift on the internal flow and cavitation phenomenon in diesel injector nozzles by CFD using RANS methods", Energy Conversion and Management 66 (2013) 246–256

[15] E. Delacourta, B. Desmeta , B. Besson, "Characterisation of very high pressure diesel sprays using digital imaging techniques", Fuel 84 (2005) 859–867