A COMPARATIVE STUDY OF PORT INJECTED AND CARBURETED TYPE LPG-DIESEL DUAL FUEL ENGINE USING CFD ANALYSIS

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ABSTRACT

The consumption of energy is increasing in exponentially due to increase in population and quality of living. Most of the energy is obtained from fossil fuels by polluting the atmosphere and thereby all living creatures. Hence there is one common goal to reduce the pollution from internal combustion engines. New technologies that use renewable sources such as solar, wind etc are being developed. Since development will take some time to realize in large scale, a cost effective method have been introduced by using gaseous fuel such as methane, hydrogen, LPG as primary fuel conventional diesel as pilot fuel. Dual Fuel Engine is found to reduce pollution such as NOx, soot, HC and power output doesn't change largely. It is found that the time required for the fuel to combust in this engine is longer than in diesel engine due to the fact that flame has to propagate from diesel to primary fuel. Also it is found that the combustion timing can be reduced if the air fuel mixture is homogeneously mixed. Hence we conducted a CFD(Computational Fluid Dynamics) study for comparing the mixing characteristics of air fuel mixture between various injector orientations at 0º,45º,135º with natural induction using venturi with one and two holes for LPG induction. The CFD results shows us that the naturally aspirated LPG induction using venturi with two holes gives us more homogeneous mixture of air and LPG than any injectors at constant rpm.

Keywords: Dual-fuel engine, Gas injector orientation, CFD, Mixture formation, LPG-AIR mixture.

INTRODUCTION

Diesel engines are used in large scale than any other type of engines around the world as power source, both in automobile and in stationary engine. This is due the ability of the engine to provide higher power output. As the source of fuel for the IC engines is from petroleum which is non-renewable. An alternate source of energy which would act during the transition from fossil fuels to clean energy is the dual fuel engine.

The government also has envisioned emission policy in the form of bharat stages, the emissions laws are becoming stricter day by day ,as the diesel engine gives out more emission like NOx ,hydrocarbon and particle emission .There are lots of effort which are done for reducing it .Even after using EGR, filters and electronic injection still it is difficult to reduce the emission drastically .Hence a viable option that exist is the dual fuel engine, which runs mostly on LPF,CNG and used diesel as pilot fuel to initialize the combustion. Since LPG and CNG are cheap and available in abundant in our country, this would save our country huge import bill.

In this engine the air is entered through the inlet manifold and LPG is injected before the inlet valve, hence the LPG-air mixer enters the cylinder. At the end of the compression stroke a small quantity of diesel fuel is injected which produces the initial flame which then initiates the LPG-air mixture to combust .The combustion in dual fuel engine is complex than the diesel engine, due to the presence of two fuels. There are two stages of combustion which is present first the diesel droplets produces the flame which induces the LPG air mixture to burn. Because of the two stages the time required for combustion is higher than normal diesel engine. The diesel pilot fuel has to be injected more before the TDC. To reduce the time of secondary combustion the homogeneous mixture of air LPG is required.

This type of engine is found to be less emitting than diesel engine, power output doesn't change drastically. More over the dual fuel engine is capable of operating in both dual fuel and in diesel mode. Depending upon the availability of fuel the operational mode can be changed. This gives us more flexibility. It is also used in shipping industries where large power output is required. In dual fuel engines only fuel injection in the inlet manifold is done since injection at cylinder caused series problem due to high temperature which damages the fuel injector.

Usually the fuel injection in the LPG consists of a secondary set of injection circuit, which consists of LPG fuel tank, fuel regulator and injector. The distance of the injector and its orientation plays a major role in homogeneous mixture of air and fuel .The maximum distance where the injector can be placed for proper operation of the engine is called injector critical distance. If the distance is more it causes good mixture before entering the cylinder which reduces the time for the secondary flame propagation. The orientation of the injector also plays a critical role. As engine speed increases the time for air fuel mixture to enter the cylinder is reduced .Hence fuel has to be injected accordingly. Failing which causes the back fire and reduction in efficiency.

METHODOLOGY

Specification of engine and fuel: For this study we have taken Kirloskar TAF1 diesel engine have been taken.

Table 1: Engine specification

	Description	Parameter value
1	Make & Model	Kirloskar TAF1
2	Type	4 stroke compression ignition diesel engine
3	No of cylinders	1
4	Rated output	4.41 KW
5	Rated speed	1500 rpm
6	Bore	87.5 mm
7	Stroke	110
8	Cubic capacity	.662 liters
9	Compression ratio	17.5:1
10	Inlet valve opening and closing	4.5deg BTDC and 35.5deg ABDC
11	Exhaust valve opening and closing	35.5deg BBDC and 4.5deg ATDC

Table 2: Fuel properties

S.No	Property	LPG
1	specific gravity	.525
2	Vapor density	1.8
3	Boiling point	20 to -27degC
4	Explosive limit	1.5-9.0
5	Molecular weight	44.09Kg/Kgmol

Design of the venturi: For comparing between the mixing characteristic of fuel in injector and naturally aspirated, we have designed a venturi for this purpose. The calculations for this venturi are as follows.

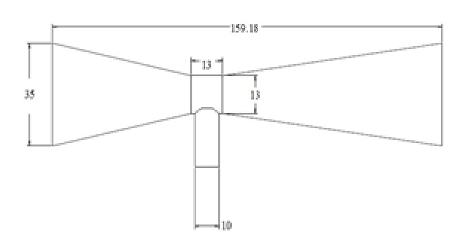

Figure 1. The venturi

Velocity of air (Va)

Q = AV - - - - - - - - - - - - - - - - - - (1)

Where A=area of flow (m^2)

V= velocity of air(m/s)

$$Q = \frac{\pi}{4} d^2 LR \quad ------(2)$$

Where d=diameter of the cylinder(m)

L=stroke length(m),

R=rps/2

Q=8.173*e-3 m3/s

Comparing eqn 1 and 2 Va=8.49m/s

Volumetric efficiency= 87%

Considering the volumetric efficiency we get Va=7.2m/s

Mass flow of air (ma)

$$m_a = Q\rho ------(3)$$

Where ρ is the density of air

$$M_a = 9.48 \times 10^{-3}\ Kg/s$$

Velocity at throatV_2

$$V_2 = \sqrt{2gh}$$

$$h = {}^{\Delta p}/_{\rho g} --------- (4)$$

Where h = head due to pressure difference

ρ = density of air

$$\Delta p = P_1 - P_2$$

P_1 = pressure at inlet (1 bar)

P_2 = pressure at throat (.975 bar)
ΔP = 2500 Pascal
H = 219m
V_2 = 65.65m/s

Diameter at the throat

From Bernoulli theorem

$$A_1V_1 = A_2V_2$$

$\therefore D_2$ = 13mm

Mass of fuel (M_f)

Air fuel ratio = 1:5(for LPG air)
Mass of fuel = mass of air * 5
M_f = 1.896e-3kg/s
Diameter of injector nozzle
ΔP = 2500 Pascal

$$\therefore h_i = \Delta P / \rho_f g$$

Hi = 106m
Velocity at injector(V_i)

$$V_i = \sqrt{2gh_i}$$

Vi = 45.64m/s

$$M_f = C_d A_i V_i \rho_f$$

$$\therefore d_i \cong 10mm$$

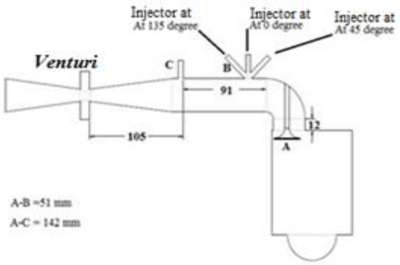

Figure 2. Schematic diagram of CFD analysis setup

Critical distance of the injector: The critical distance of injector plays a major role in the mixing characteristics of the air and fuel. If the injector is placed closer to the inlet valve then mass fraction of fuel in air is very low and does not give good mixture. If it is placed in very large distance from the inlet valve good mixture is obtained. This seems to increase as the injector is moved from the inlet valve hence the critical distance has to be found out. The start and duration of injection (DOI) plays a vital role in finding the critical distance of the injector. More over in dual fuel engine as explained earlier the flame propagates from diesel droplets to the surrounding air LPG mixture. This poses a significant challenge in positioning and timing of the fuel injectors because if the air fuel mixture is homogeneously mixed before entering the cylinder it will give faster combustion than when mixing takes place in the cylinder.

Theoretical calculation of the critical injector

$$t_a = (d\theta_{av} \times 10^3)/(6N)$$

Where
t_a= time available for the fuel to enter the cylinder
N= rpm of the engine
Time taken by the fuel to travel to the cylinder per cycle is given by

$$t_t = D / V_{mix}$$

Where
D= distance from the inlet valve
Vmix= velocity of the mixture
From the above equations we get
critical distance =153 mm

The injector location also has to satisfy the following condition $t_a > t_t$ because if this is not satisfied there will be fuel left in the inlet manifold after the closing of inlet valve hence back fire will take place.

CFD ANALYSIS

Modeling of combustion chamber and inlet manifold is done in Pro-E. We consider the symmetry of the combustion chamber and the manifold. Meshing is done on ANSYS and CFD stimulation is done on Fluent, both available in ANSYS Workbench 14. Total nodes are 11955 and elements 57272. We used advanced sizing function on curvature. In fluent we used species transport model. The assumption made is the fluid is incompressible and no chemical reaction between air and LPG. In ANSYS FLUENT the local mass fraction of each species, Yi, is predicted through the solution of a convection-diffusion equation for the k^{th} species. This conservation equation takes the following general form.

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

Y_i- Mass of species i/total mass of all the species
R_i-The net rate of production of species k by chemical reaction
S_i-The rate of creation by addition from the dispersed phase
J_i- The diffusion flux of species k, due to the gradients of concentration and temperature
The problem setup contain propane-air mixture with 5 species (nitrogen, water vapour, carbon dioxide, oxygen, propane)

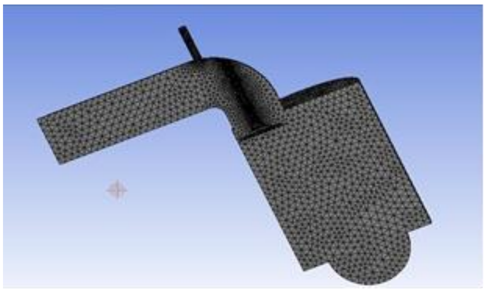

Figure 3. mesh

The standard k-εmodel developed by Launder and Spalding is used to determine the turbulence kinetic energy k and its energy dissipation ε. CFD study was carried out for finding out the better mixing characteristics between the naturally aspirated LPG-DI engine using venturi with single and two hole and injector with 2bar pressure. The positions of the injector location considered for study are 51mm (at 45 degree, 0 degree and 135 degree inclinations), 142mm and 59mm (below) from A.

RESULTS AND DISCUSSION

Analysis of Mass fraction: Fig 4-9 shows the contours of mass fraction of LPG. Fig 4-7 shows the mass fraction of LPG with different injector orientation and at various distance and fig 8-9 shows the contour of mass fraction of LPG with venturi The fig 4,5 shows better mixing due to the turbulence and diffusion effect. Mixing of LPG with air stream is characterized using diffusion, molar concentration and turbulence. Here better mixing is used in the sense that the homogeneity of inducted air with gaseous fuel. In all the below figures having injectors oriented at 0^o and 45^o have highest diffusion due to high momentum which opposes main air flow. Fig 6 shows injector orientation at 135 degree. It is having poor mixing of gaseous fuel because there is no opposing momentum. Here we can see that the mass fraction of LPG is high near the valve stem area.

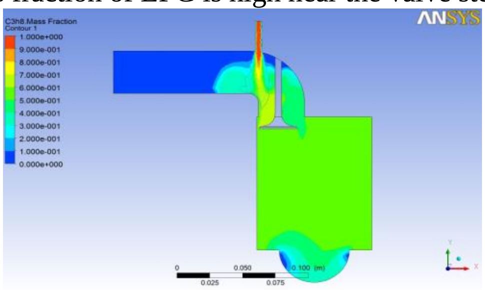

Figure 4. Mass fraction of LPG when injector at 00

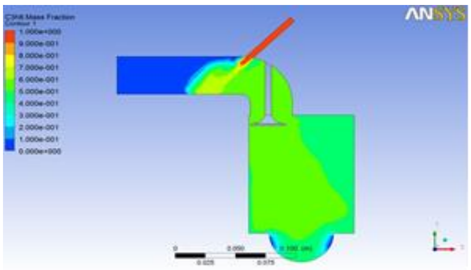

Figure 5. Mass fraction of LPG when injector at 450

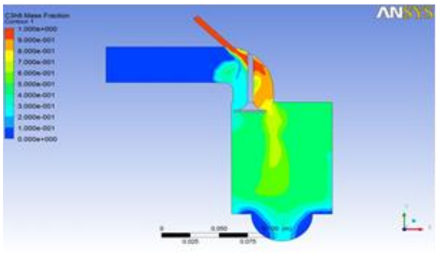

Figure 6. Mass fraction of LPG when injector at1350

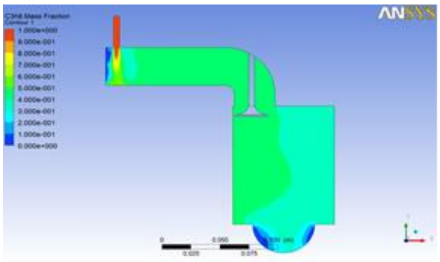

Figure 7. Mass fraction of LPG when injector at 142mm away from inlet valve

In the Fig 7, the injector is located at a distance of 142 mm from A. As already mentioned it is well within the critical distance which is 153 mm. If we place injector beyond this there will not be sufficient time for the homogeneous mixture to enter the cylinder. Hence back fire occurs and efficiency of engine considerably reduces. The location of the injector in the inlet manifold plays a vital role in the formation of homogeneous mixture. As the distance of injector increase from the inlet valve, there will be sufficient time for the formation of homogeneous mixture. But there is a chance that the whole mixture wouldn't enter inside the cylinder chamber during the suction stroke. Fig 8 shows the mixing of LPG with air using venturi with one inlet hole at the throat area. The variation of mass fraction is not very smooth, which shows poor homogeneous mixing. Fig 9 shows the venture with 2 inlet hole for LPG. The high pressure drop created at throat; make sure proper suction of LPG and thereby good mixing quality.

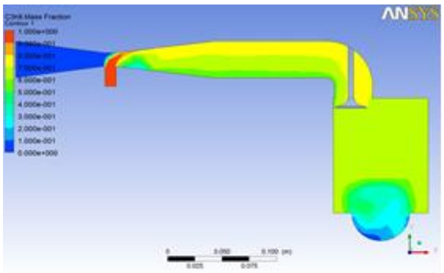

Figure 8 Mass fraction of LPG when venturi (with one LPG inlet) at 142mm away from inlet valve

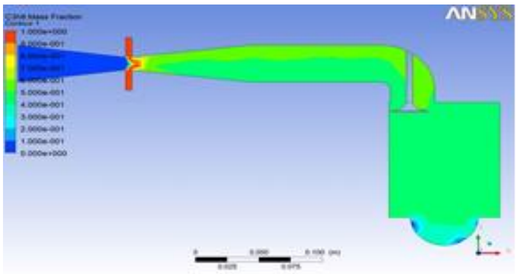

Figure 9 Mass fraction of LPG when venturi (with two LPG inlet) at 142mm away from inlet valve

Analysis of Velocity

Mixing species velocity play a vital role in fuel air transport, this comprises an integral part of combustion. Comparing the Fig 10, 11& 12, we can notice that the velocity of figure 12 is more. This is mainly due to the lesser travelling distance of the gaseous fuel. Time taken by the mixture velocity to reach the cylinder chamber depends upon the mixture velocity for the particular distance. So we need to compromise between the gas travelling distance and mixture formation to take place .So the injector design should be such that the required amount of fuel will reach the cylinder within the stipulated time per cycle in order to avoid the accumulation of fuel and avoid any chances of back fire which are opposite to each other and perpendicular to the flow.

Fig 14 & 15 shows a wide velocity stream of LPG. So there will be enhanced mixing of LPG and air

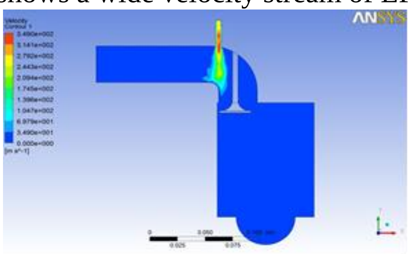

Figure 10. Velocity contour when injector at 00

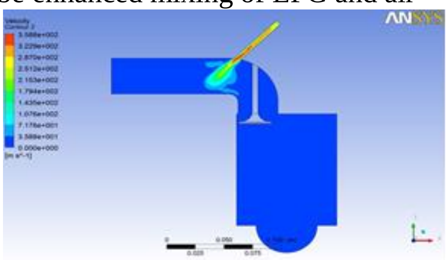

Figure 11. Velocity contour when injector at 45 0

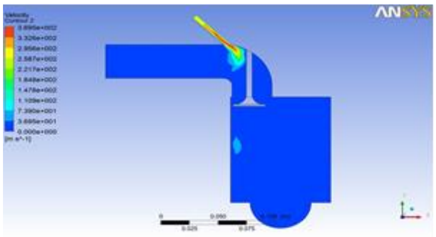

Figure 12. Velocity contour when injector at 1350

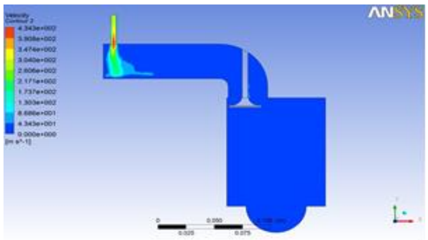

Figure 13. Velocity contour when injector at a distance 142mm from inlet valve

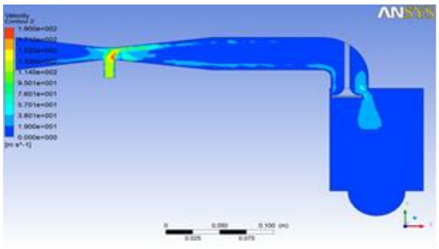

Figure 14. Velocity contour when venturi (with one LPG inlet) at 142mm away from inlet valve

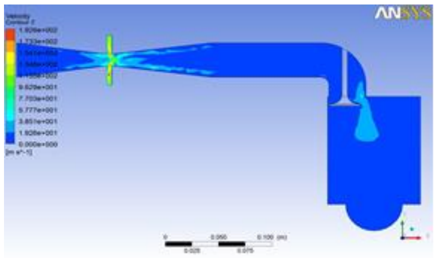

Figure 15 Velocity contour when venturi (with two LPG inlet) at 142mm away from inlet valve

Analysis of turbulence intensity

Molecular level mixing of LPG and air is required in order to have a better combustion. The turbulence will make sure the proper mixing of LPG and air.

In fig 16 the injector is oriented at 0°, placed at a distance of 143mm shows turbulence intensity very low due to the fact that there is no opposing moment to the air. In Fig 17 due to opposing moment of the fuel in the air there is large turbulence.

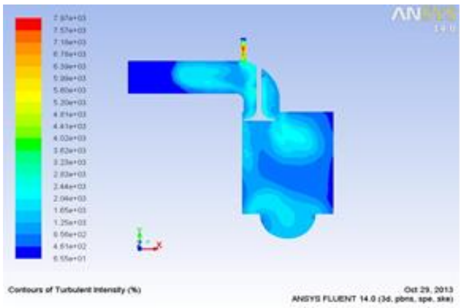

Figure 16. Turbulent Intensity Contour when injector at 00

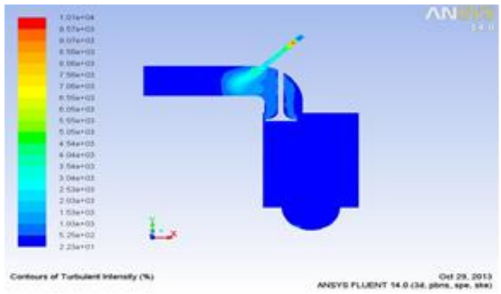

Figure 17. Turbulent Intensity Contour when injector at 450

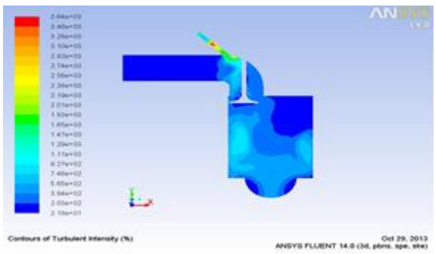

Figure 18.Turbulent Intensity Contour when injector at 1350

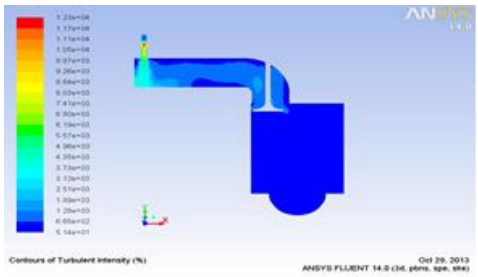

Figure 19. Turbulent Intensity contour when injector at a distance 142mm from inlet valve

In Fig 20, 21 venturi with single and two holes the turbulence counters shows the intensity at throat higher in two holed than in single holed. This is due to the moments of fuel entering through the opposite holes is perpendicular to moment of air which is higher in throat hence we can get better homogeneous mixing in venturi with two holes.

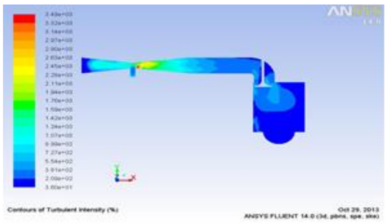

Figure 20.Turbulent intensity contour when venturi (with one LPG inlet) at 142mm away from inlet valve

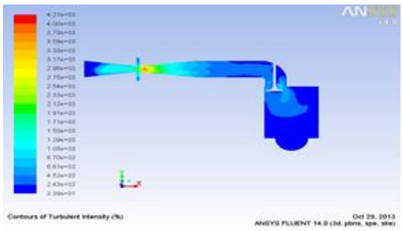

Figure 21. Turbulent intensity contour when venturi (with two LPG inlet) at 142mm away from inlet valve

CONCLUSION

From the analysis we conclude that the venturi offers good turbulence and mixing of air and fuel than port injection at different angles. Port injection at 135 deg gives more homogeneous mixture than any orientation of injectors. Two holed venturi gives more homogeneous mixture than single holed venturi. By increasing the number of holes in venturi we can increase the turbulence and mixing.

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