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Research Article

Computational Analysis for Mixing of Air and Producer Gas through an Intake Manifold of Different Geometries

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Abstract

Producer Gas Engines are gaining more and more demand in present day to day life. Proper mixing of Producer Gas and Air is very important for obtaining the combustible air-fuel mixture in an engine. Design of Intake manifold of an engine plays an important role in obtaining proper air-fuel mixture. Different geometrical parameters can be altered or modified for achieving the proper mixing of fuel and air. Computational Fluid Dynamics (CFD) simulation technique is one of the most widely used software simulation technique for such an analysis. CFD Simulation provides the feasibility of using combinations of different geometrical parameters with time saving also. In this paper, a computational study for good mixing of air and producer gas for T shape of Intake manifold for air inlet pipe length of 75mm, 100mm and 150mm is carried out at mixing lengths of 50mm, 100mm, and 150mm. The simulation is done for same input data for all types of Intake manifolds. The analysis showed that for different geometries different mixing lengths are obtained for good mixing. The results showed that the optimum mixing length of 100mm for an air inlet pipe length of 75mm gives proper and uniform mixing of air and producer gas than other combinations. This shows that mixing is strongly dependent on the geometry of the Intake manifold of the engine.

Keywords: *Producer gas, Producer Gas Engine, Computational Fluid Dynamics, Mixing length, Intake manifold.*

1. Introduction

The use of renewable energy sources to produce electrical energy is increasing day by day. It is not because of depletion of fossil fuels but also due to pollution concerns raised by the use of fossil fuels. Bhide Anjali, Monroy R. Carlos. (2011) have investigated that biomass energy is highly demanding energy today as it is available in abundant quantity in different forms on the earth. Much of the biomass goes in waste in earth without being utilized for energy generation. This is because of the very little technical developments happened in the conversion of this biomass into useful form of fuel over many of the past few years. Some researchers have paid attention to this energy source as a fuel for reciprocating internal combustion (IC) engines for power generation in rural areas. Gasifier is used for obtaining the gaseous form of fuel known as Producer Gas from Biomass by Thermochemical conversion process. The Producer gas obtained from gasification may be used for external combustion as well as for internal combustion. Air is required for combustion of Producer Gas and mixing of air with producer gas is generally obtained in an Intake manifold of Internal Combustion engines. There has been ongoing research on the engine's performance running on gaseous fuel. As the combustion efficiency is directly proportional to the degree of homogeneous mixing, it is important to make sure that the air and producer gas are homogeneously mixed prior to entry to the combustion chamber. The present work is aimed at analyzing the flow behavior of producer gas and air in the prototype mixer to determine its feasibility. The computational modeling approach has been applied. For proper mixing of producer gas and air, different types of Intake manifold geometries have been suggested by many researchers. A brief review of work done in the field is reported in this section.

2. Literature Review

Sheshagiri G.S. (2009) at IISc Bangalore have designed an experimental setup of the carburetor which consists of the T-shaped gas supply line containing different valves for flow control of the gas and air. This was a simple experimental arrangement for air and producer gas entry used for enhanced mixing of the air and producer gas. V. S. Yaliwal (2014) have presented the effect of producer gas on the performance of the engine for different carburetor modifications like Y – shaped and parallel flow gas entry type carburetors. They found from the experimental results of gasifier – engine system tests that parallel flow gas entry carburetor was

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*Corresponding author: **S. J. Suryawanshi** found to be optimum compared to Y – shaped carburetor. CFD simulations of Y – shaped and parallel flow gas entry type carburetors were also done which showed good agreement with the experimental results obtained. T. R. Anil (2006) have done a CFD modeling for designing a producer gas carburetor which was comprehensively analyzed for its mixing performance and response. The carburetor consists of a mixing chamber for which there was a radial entry for Producer gas and a tangential entry for air inlet. The experimental observations were in well accordance with the simulated results of the designed carburetor. P. R. Bhoi (2008) have designed a 150kW capacity premixed burner with producer gas as a fuel with swirler vane arrangement for better mixing of air and producer gas for Gas Turbine application. Different combinations of swirler vane angles and were it is observed from the literature review that much of the work related to Producer gas carburetor cum mixer is done experimentally without utilizing proper simulation tool. In some of the literature papers CFD simulation is done for the air-producer gas carburetor cum mixer, but they are very few and not upto the mark. The design of the producer gas-air mixing device cum carburetor can be very well done with a proper CFD simulation technique. In this paper, a detailed CFD simulation of a Producer gas carburetor of T shape for various geometrical combinations have been done and presented for its further practical use also.

3. Composition and Material properties of Producer Gas and air

Air and Producer gas are the working fluids. The material properties of air and producer gas are as follows.

Table 1 Volumetric Composition of Air and Producer Gas

Component	Air (%)	Producer Gas (%)
Carbon Dioxide	0.03	12.58
Carbon Monoxide	0.01	17.31
Hydrogen	0	16.82
Methane	0	1.87
Oxygen	20.71	0
Nitrogen	79.25	51.43
Total	100	100

Table 2 Conversion of Volumetric Composition to Gravimetric Composition

Component	Volumetric Composition(%)	Gravimetric Composition(%)
Carbon Dioxide	12.58	21.92
Carbon Monoxide	17.31	19.19
Hydrogen	16.82	0.67
Methane	1.87	1.19
Oxygen	0	0
Nitrogen	51.43	57.03
Total	100	100

Table 3 Specific Properties of Air and Producer Gas

Property	Air	Producer Gas
Density (kg/m^3)	1.175	0.978
Viscosity(Pa.s)	1.179 X 10^-5	1.452 X 10^-5
Specific Heat(J/Kg-k)	1005.148	3838.358
Thermal Conductivity (kW.m/K) Conductivity(W/m-K)	0.0248	0.0535

4. Design of T Shape Producer gas-air Carburetor

The process of forming a combustible Air-Fuel Mixtures by mixing the right amount of fuel with air before admission to the cylinder of the engine is called carburetion and the device doing this job is called carburetor. The various factors affecting the process of carburetion are

1. Engine speed
2. Vaporization characteristics of the fuel
3. Temperature of incoming air
4. Design of the carburetor

Since the engines are of high speed type there is very little time available for mixture preparation. So to have a high quality carburetion the velocity of the air at point of injection of fuel has to be increased. To achieve this, a venturi is provided in the path of air. The pressure and temperature of the surrounding air also affects the process of carburetion. Higher atmospheric air temperature increases the vaporization of the fuel and hence a more homogeneous mixture is produced. Design of the carburetor, its intake system and the combustion chamber also affect the uniform distribution of mixture to various cylinders of the engine. The carburetor used must be developed in such a way that, it should give air and producer gas mixture at stoichiometric and at an ambient conditions for a particular engine depending on engine operating conditions (load and speed conditions). The carburetor designed for producer gas must have an ability to maintain smooth operation with minimal pressure loss and on-line provision for air/fuel tuning during the operation. The carburetor that is designed in the present work is a T shape type (Figure 1). Air enters the mixer through the main inlet and Producer gas enters at a 90 degree angle to the air flow. The design of the intake system of the pipe is done for the following specifications of the engine.

Table 4 Specifications of the Engine

Spark Ignition Engine	
Parameters	Specification
Type of engine	Spark Ignition
No. of Cylinder	4
Rated power	53.2 KW @ 4800 RPM
Max Torque	132.2 Nm
Swept Volume	1817cm3
Aspiration	Natural

Acc. to the Table no.1, Producer gas consists of CO (19.19%), H2 (0.67%), CH4 (1.19%), N2 (51.43%), CO2 (21.92%). The stoichiometric air-fuel ratio required for complete combustion of fuel is found to be 1.138.

Discharge of air,

$$Q_a = \frac{\eta_v * V_d * N}{n} \qquad (1)$$

$$Q_a = \frac{0.85*1817*10^{-6}*4800}{2*60}$$

$$Q_a = \frac{3.70}{60} \ m^3/s$$

$$Q_a = 0.0617 \ m^3/s$$

Mass flow rate of air,

$$\dot{m}_a = \rho * Q = \frac{4.44}{60} Kg/s \qquad (2)$$

$$\dot{m}_a = 0.0726 \ Kg/s$$

Mass flow rate of fuel,

$$\dot{m}_f = \frac{\dot{m}_a}{1.138} = \frac{0.0726}{1.138} = 0.0637 \ Kg/s$$

$$\dot{m}_f = 0.0637 \ Kg/s$$

Velocity of air,

$$V_a = M * C$$

$$V_a = 0.1 * 340$$

$$V_a = 34 \ m/s$$

Diameter of air pipe,

$$Q_a = A * V_a \qquad (3)$$

$$0.0617 = A * 34$$

$$A_a = 1.8147 * 10^{-3} \ m^2$$

$$d_a = 0.048 \ m = 48\text{mm}$$

Diameter of Producer gas pipe,

$$\frac{\dot{m}_a}{\dot{m}_f} = \frac{A_a}{A_f} * \sqrt{\frac{\rho_a}{\rho_f}} \qquad (4)$$

$$A_f = (1.138 * 1.8147 * 10^{-3})$$

$$d_f = 0.0418m = 41.8mm \approx 42mm$$

5. CFD Analysis

The CFD technique is based on the numerical solutions of the fundamental governing equations of fluid dynamics, namely the continuity, momentum and energy equations. CFD has previously been successful in solving many complex engineering problems that are difficult to analyze experimentally. The Gambit-fluent software package of CFD is used to the current work for the analysis. The fluent flow solver is a finite volume, pressure based, fully implicit code solving the 3D Navier-Stokes equations governing fluid flow and associated physics. The code is used for the modeling of a wide range of industrial problems involving fluid flow, heat transfer (including radiation), turbulence, mixing of chemical species, multi-step chemistry, two-phase flows, moving/rotating bodies and other complex physics.

The assumptions made in the present simulations are as follows:

i. Turbulent flow - This involves the use of a turbulence model, which generally requires the solution of additional transport equations. The k-Ɛ transport equation (Jones & Launder, 1972; Launder & Sharma, 1974) was used in the study. This model was practical for many flows and relatively simple to implement and easy to converge. Three quantities, turbulent kinetic energy (K), dissipation rate (D) and length scale (L), are very important in specifying the turbulence characteristics at the inlet. If K and D values are specified, the value for L is ignored. It is sometimes more convenient to provide a length scale instead of a value for the dissipation rate. The length scale that would be used for an internal flow is usually the inlet diameter or height.

ii. Mixing flow without reaction - This requires the solution of additional equations for mixture fractions or species mass fraction. In this simulation, it is assumed that there is no reaction between air and producer gas. The model used for this is species transport model.

iii. Incompressible - As the speed involved is reasonably low, it is adequate to assume that the fluids are incompressible. With incompressible flow, the density of fluids is constant and it activates a pressure correction equation.

Here, the simulations are carried out for various air intake pipe lengths (50mm, 100mm and 150mm) and mixing pipe lengths (50mm, 100mm, 150mm) and the results are compared for the contours of mass fractions of CH_4, H_2, CO, CO_2, O_2 and N_2 for various combinations.

Modeling

The geometry was modeled using Gambit modeling software. The continuous tetrahedron meshed model considered for CFD analysis of two cases out of total nine cases is shown in Fig.1 with 15876 and in Fig.2 with 19551 computational nodes respectively.

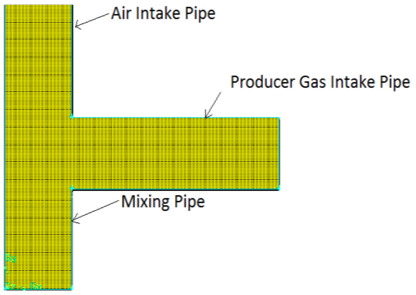

Fig.1 Modeling and Meshing of T Shape Carburetor [Air Intake pipe (75mm) & Mixing pipe (50mm)]

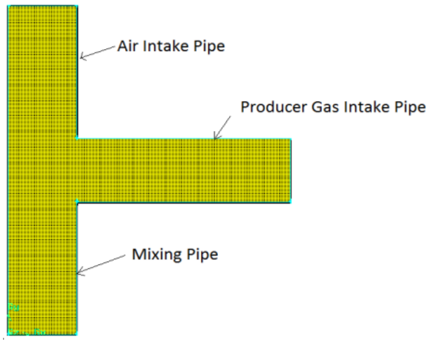

Fig.2 Modeling and Meshing of T Shape Carburetor [Air Intake pipe (100mm) & Mixing pipe (100mm)]

Input and Boundary Conditions

i. Air inlet boundary - It is assumed that the conditions at the inlet boundary are fixed. For the fixed mass flow rate condition, the flow solver determines the pressure, temperature and density applied to each face of the boundary.

ii. Producer Gas inlet boundary - Fixed static pressure inlet boundary conditions are used at the fuel inlets. By using this boundary condition type, the mass of the fuel inducted will form part of the solution.

iii. Outlet boundaries - The fixed pressure outlet boundary conditions serve to anchor the system pressure and allow both inflow and outflow to satisfy continuity in the domain. Since fixed pressure outlet boundaries can also allow inflow, it is important to provide realistic values of turbulence quantities, temperature and mixture at these boundaries even though they are not required. These values are only used to evaluate diffusion at the boundary.

6. Results and Discussions

The distribution of concentration of different components of Producer Gas through the T shape carburetor for different combinations of air intake pipe length and mixing pipe length was simulated. The contours of mass fractions of CH_4, H_2, CO, CO_2, O_2 and N_2 for various combinations are shown in the graphical format as below.

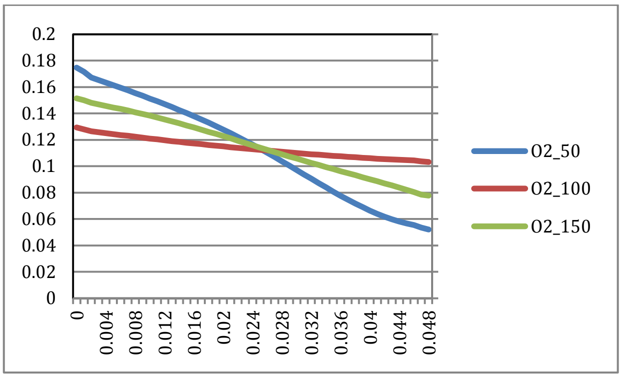

Fig.3 Mass Fraction of O2 along X-axis (For 75mm Air Intake Pipe Length)

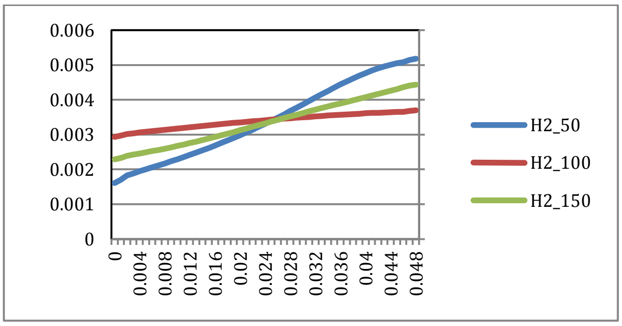

Fig.4 Mass Fraction of H2 along X-axis (For 75mm Air Intake Pipe Length)

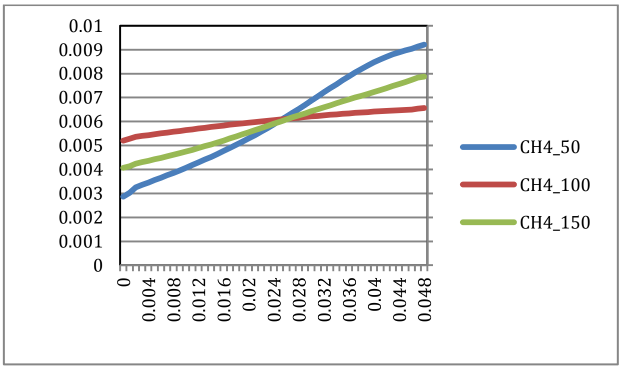

Fig.5 Mass Fraction of CH4 along X-axis (For 75mm Air Intake Pipe Length)

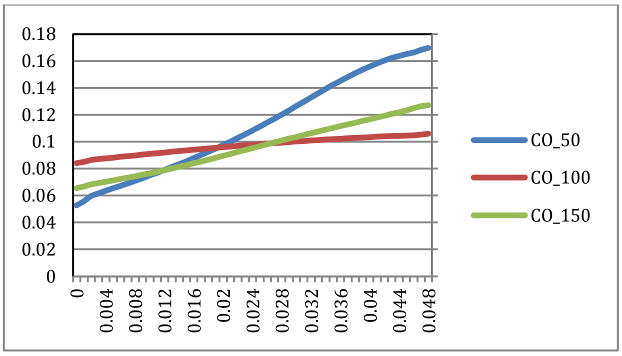

Fig.6 Mass Fraction of CO along X-axis (For 75mm Air Intake Pipe Length)

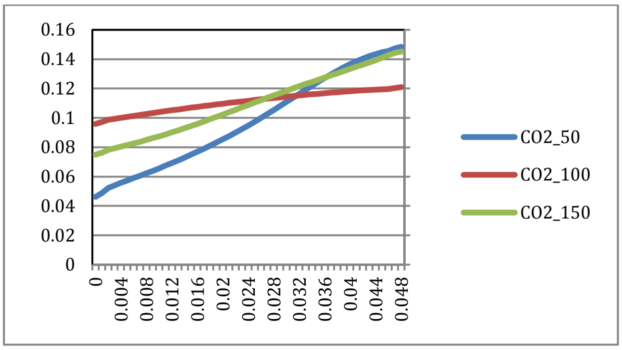

Fig.7 Mass Fraction of CO2 along X-axis (For 75mm Air Intake Pipe Length)

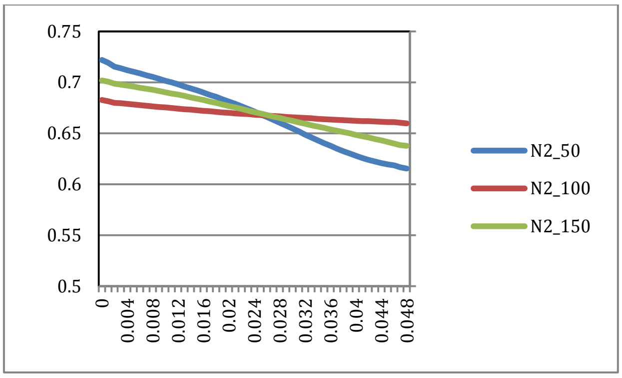

Fig.8 Mass Fraction of N2 along X-axis (For 75mm Air Intake Pipe Length)

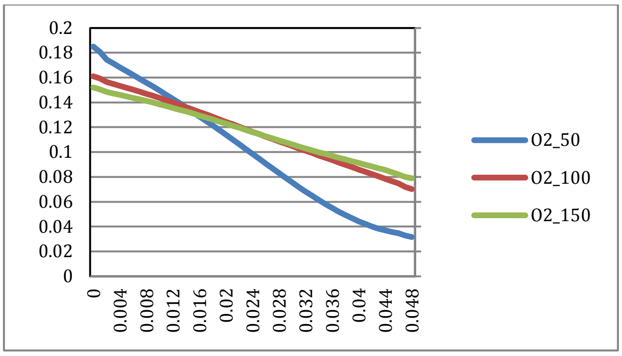

Fig.9 Mass Fraction of O2 along X-axis (For 75mm Air Intake Pipe Length)

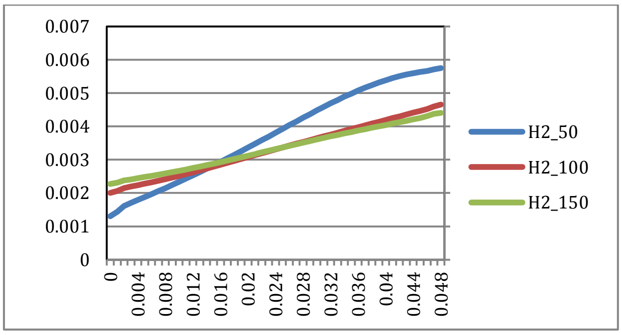

Fig.10 Mass Fraction of H2 along X-axis (For 100mm Air Intake Pipe Length)

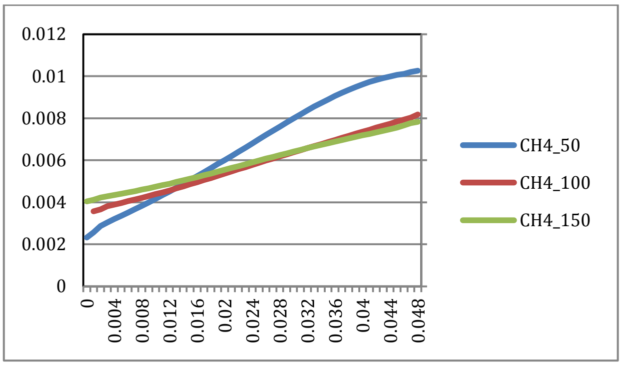

Fig.11 Mass Fraction of CH4 along X-axis (For 100mm Air Intake Pipe Length)

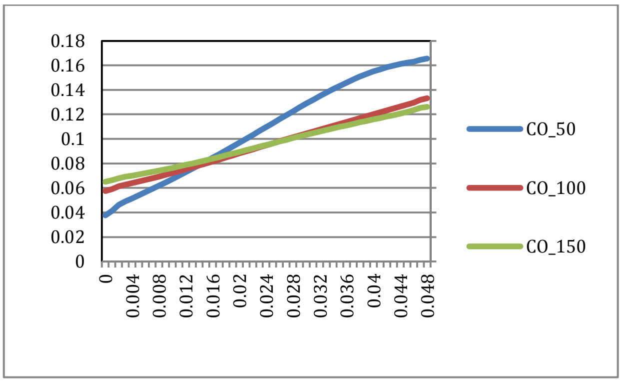

Fig.12 Mass Fraction of CO along X-axis (For 100mm Air Intake Pipe Length)

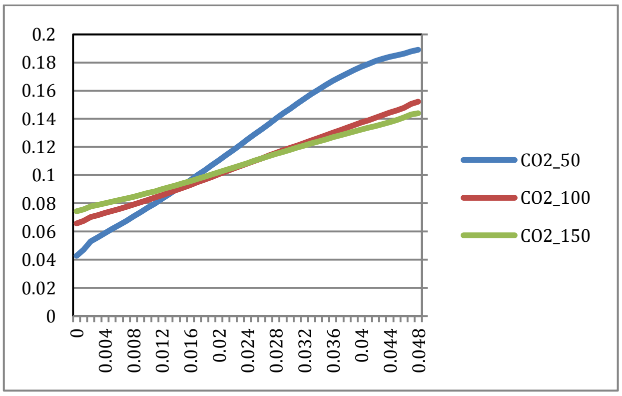

Fig.13 Mass Fraction of CO2 along X-axis (For 100mm Air Intake Pipe Length)

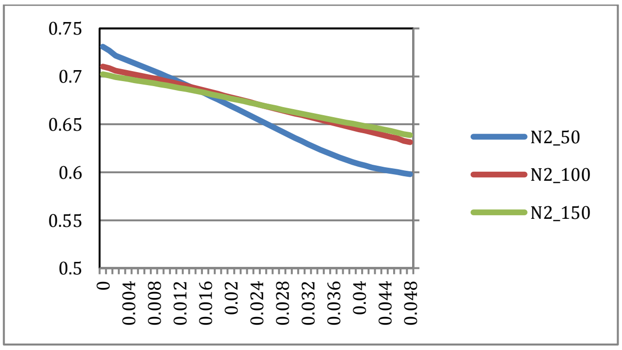

Fig.14 Mass Fraction of N2 along X-axis (For 100mm Air Intake Pipe Length)

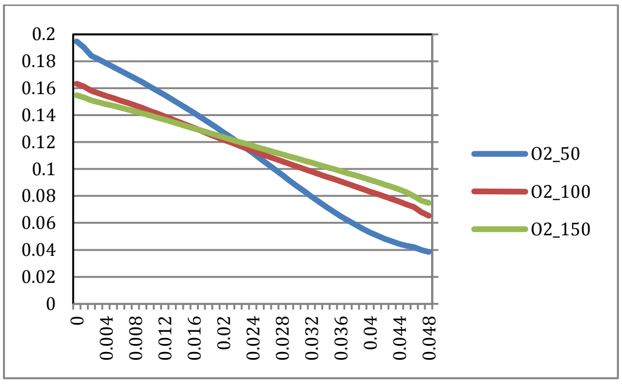

Fig.15 Mass Fraction of O2 along X-axis (For 100mm Air Intake Pipe Length)

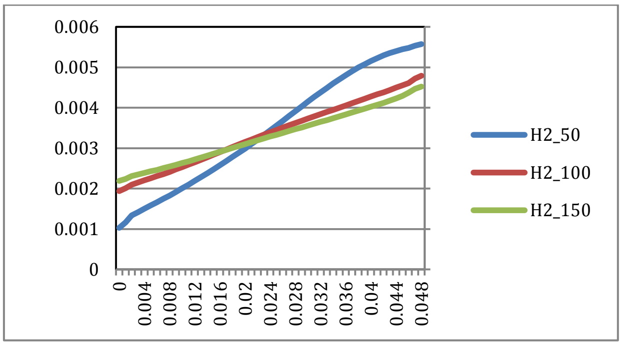

Fig.16 Mass Fraction of H2 along X-axis (For 150mm Air Intake Pipe Length)

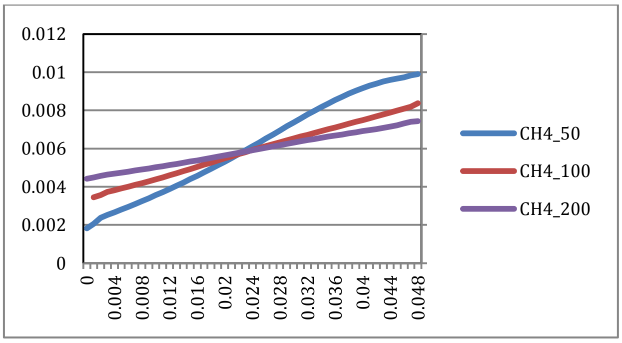

Fig.17 Mass Fraction of CH4H2 along X-axis (For 150mm Air Intake Pipe Length)

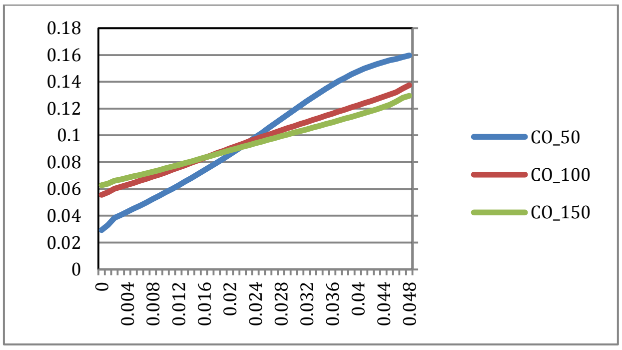

Fig.18 Mass Fraction of CO along X-axis (For 150mm Air Intake Pipe Length)

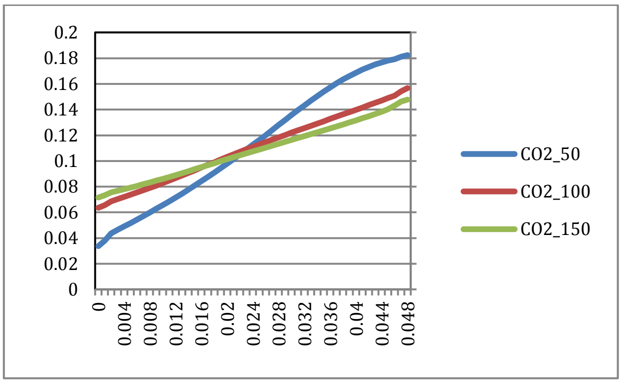

Fig.19 Mass Fraction of CO2 along X-axis (For 150mm Air Intake Pipe Length)

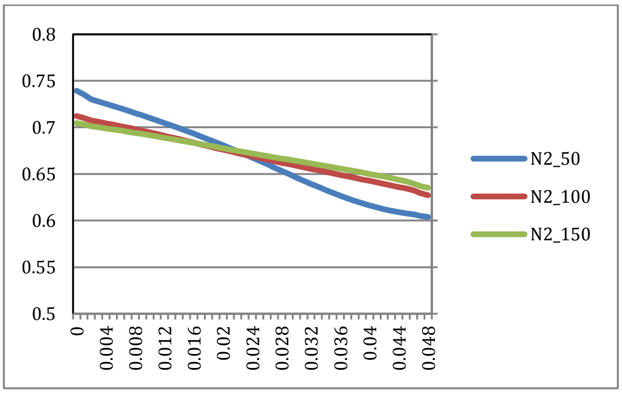

Fig.20 Mass Fraction of N2 along X-axis (For 150mm Air Intake Pipe Length)

The mixing in a pipe is found to be homogeneous when there is uniform concentration distribution across the plane of the pipe. The variation of concentration of the component across that plane should be minimum for uniform mixing to happen. The simulated results from above graphs of all the combinations show that there is minimum variation across the mixing plane for an air intake pipe of 75mm length and for mixing plane length of 100mm. Hence the T shape carburetor with intake pipe length of 75mm and mixing pipe length of 100mm can be selected as an optimum one. Thus the CFD simulation is the best tool for obtaining the homogeneous mixing of different components of the Producer gas with air.

Conclusions

From the CFD analysis done for Intake piping system of Producer Gas Engine, following conclusions can be drawn:

1) Optimization of geometrical parameters is essential for achieving good air-fuel mixing leading to proper combustion.
2) CFD analysis is a good technique to obtain optimum geometry of intake manifold.
3) It is visibly shown that there is significant effect of varying the geometrical parameters of intake manifold on mixing of producer gas with air.

4) The variation of air intake pipe length from 75mm to 150mm with 25mm increment in length showed that the uniform mixing is obtained for 75mm air intake pipe length.
5) From the results obtained, it could be concluded that CFD simulation gives good insight of air-fuel mixing inside the T shape Producer gas-air mixer which can be very much useful at the time of actual fabrication of intake manifold saving the cost as well as time also.

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