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Analysis of effect of air-fuel ratio on two different designed producer gas carburetors using CFD

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ABSTRACT

In the present situation emission affects a lot to the environment, so we need to reduce emission effect on the environment as much as possible. In this regarding it is found that Biomass is one of the viable and sustainable renewable resources. Producer gas produced from gasification system clean enough to be used in Direct Injection gas engines. To use the producer gas we have to do some changes in specialized components that require modification need be studied. Carburetor is one of the important components in such category and we need to establish a design procedure for this application. The work presented here is an effort in this regard. A specially designed producer gas carburetor is comprehensively analyzed for its mixing performance and response with a CFD modeling. The model is made up of a mixer chamber that has the essential orifices for air and fuel (producer gas) inlets to generate stable stoichiometric mixture at near to ambient conditions using the induction of the engine as the driving pressure differential for the flow, and tested for a case of engine of 25kWe capacity. The CFD simulations are carried out to validate the FLOW analysis inside the producer gas carburetor for different designs. The results show a good insight into the flow details and have paved way in optimization in the geometrical design to get a good mixing efficiency.

Keywords: Carburetor, CFD, Producer Gas, Air/Fuel ratio, Turbulence

1. INTRODUCTION

In the recent times, gaseous fuels are gaining prominence as cleaner fuels for power generation via internal combustion engine route. Current state of technological advances, it is recognized that Biomass is one of the viable and sustainable renewable resources and new technologies emerging out of biomass based gasification systems find a significant role in bridging the energy crisis. However under present conditions, economic factors seem to provide the strongest argument of considering gasification. In many situations where the price of petroleum fuels is high or where supplies are unreliable the biomass gasification can provide an economically viable system – provided the suitable biomass feedstock is easily available.

The advanced biomass gasification systems are known to generate producer gas as the combustible fuel that is clean enough to be used in Direct Injection gas engines. However in order to adapt standard gas engines few of its components need modifications before they are used in the biomass power plants. Since this area is an emerging one and the technology has not been disseminated to the scale of driving market, it is essential that specialized components that require modification need be studied. Carburetor is one of the important components in such Category and it is identified that additional research work is to be carried out in establishing a design procedure for this application.

The technology of biomass gasification has existed for more than seventy years. Some of the work done during World War II. Subsequently to World War II, the technology did not gain popularity on two counts, the first reason being unrestricted availability of petroleum fuels the world over at a low cost. The other reason being, technological problems related to the presence of high level of tar content in the product gas, which posed a threat to engine operations.

In the recent times, gaseous fuels are gaining prominence as cleaner fuels for power generation via internal combustion engine route; the power generation package including both reciprocating engines and gas turbine machinery. Complete combustion with minimal emission is the key feature of gaseous fuels and this feature is currently being exploited the world-over for power generation purposes. Among the clean sources of fuel for power generation, natural gas has been exploited largely due to significant availability in specific locations.

Similarly, there is also an impetus on using gas generated from industrial and municipal wastes, namely diluted natural gas – biogas and land-fill gas. As distinct from gas generation from biological/organic wastes by biological conversion process, which is limited to non-loganiaceous matter, the thermo chemical conversion route (also termed gasification) can process any solid organic matter. The range of biomass includes agro-residues like rice husk, sugarcane trash and bagasse in compact or briquetted form. The resultant gas known as 'Producer gas' can be used for fuelling a compression ignition (CI) engine in dual-fuel mode or a spark ignition (SI) engine in gas alone mode. Harnessing of energy from biomass via gasification route is not only proving to be economical but also environmentally benign friendly.

Internal combustion reciprocating engines have integrated into societal service in the last century. Their use has improved the quality of life substantially, but at the cost of degradation to the environment, certainly in several countries with insufficient environmental consciousness. Therefore, large impetus is being given to improve the efficiency and thereby reduce the emissions by using two approaches namely, improvement in engine design and use of alternate fuels in place of fossil fuels.

In the domain of alternate fuels, oxygenated liquid and gaseous fuels receive more prominence because of the possibilities of cleaner combustion. Among the gaseous fuels, producer gas, a low-energy density gas derived from biomass holds a large promise as an environment friendly fuel. This fuel gas in addition to being CO_2 neutral generates lesser quantum of undesirable emissions. Even though these merits of biomass have been recognized widely, the technological capitalization has remained in infancy largely.

The thermo-chemical conversion of biomass leads to a gas generally termed as producer gas. The process is termed gasification implying that a solid fuel is converted to a gaseous fuel. In the recent times, there is a renewed interest in biomass gasification technology, which has stimulated interest in producer gas operated engines.

The range of biomass includes agro-residues like rice husk, sugarcane trash and bagasse in compact or briquetted form. The resultant gas known as 'Producer gas' can be used for fuelling a compression ignition engine in dual fuel mode or a spark-ignition (SI) engine in gas alone mode.

Air/fuel ratio characteristic exert a large influence on exhaust emission and fuel economy in Internal Combustion engine. With increasing demand for high fuel efficiency and low emission, the need to supply the engine cylinders with a well defined mixture under all circumstances has become more essential for better engine performance. Carburetors are in general defined as devices where a flow induced pressure drop forces a fuel flow into the air stream. An ideal carburetor would provide a mixture of appropriate air-fuel (A/F) ratio to the engine over its entire range of operation from no load to full load condition. To ensure proper performance, Carburetor should be reproducible and have unequivocal adjustment procedures.

CFD software used for flow analysis is ANSYS FLUENT. The k-ε RNG turbulence model is used and is considered to be the best model between computational time and precision. The geometric model is built using ANSYS workbench.

1.1. Biomass Gasifier

Biomass gasification is a process characterized by high temperature (700-1000 ^{0}C) and partial combustion in which solid biomass usually in the form of pieces of wood or agricultural residue is converted into a combustible gas mixture is called as producer gas. The main constituents of producer gas are carbon monoxide, carbon dioxide, hydrogen and nitrogen. The device in which producer gas is produced is called as gasifier. The gasifiers can be classified into two categories: Fixed bed gasifier and fluidized bed gasifier. The fixed bed gasifiers are further classified into three categories: Up draft, down draft and cross darft.

1.2. Producer Gas Fuel

Producer gas obtained from incomplete combustion of biomass, typically contains 18-20% each of H2 and CO, 2% CH4 and, rest inert like CO2 and N2. The lower calorific value varies between 4.5 – 4.9 MJ/kg, with stoichiometric air-to-fuel ratio being 1.25 + 0.05 on mass basis. Some of the fundamental data relating to producer gas are compared with pure gases. The comparison of producer gas with methane is more vital with regard to the internal combustion engine operation. This is because most of the engines operating on gaseous fuels are either close to pure methane (natural gas) or diluted methane (bio-gas, land-fill gas). The fuel-air equivalence ratio (actual fuel to air ratio)/(stoichiometric fuel to air ratio) at the flammability limits compares closely for both the gases, but the laminar burning velocity for producer gas at the lean limits is much higher. The laminar burning velocity for producer gas (at 0.1MPa, 300K) is about 0.5 m/sec, which is about 30% higher than methane. This feature is argued to demand lower advancement in the ignition timing and needs consideration while arriving at the optimum ignition timing for the producer gas fuel.

Like any other gaseous fuel, producer gas can be used for internal combustion engine operation provided the gas is sufficiently clean such that contaminant does not accumulate in the intermediary passages to the engine cylinder. But this fuel has largely been left unexploited due to additional perceptions, namely auto-ignition tendency at higher compression ratio (CR), large de-rating in power due to energy density being low. However, these perceptions need re-examination and clarification. The arguments against the classical view in favour of better knock resistivity are as follows. Firstly, with the laminar burning velocity being high due to the presence of hydrogen (more so, with the gasifier system adopted in this work) might reduce the tendency for the knock. Secondly, the presence of inert in the raw gas (CO2 and N2) might suppress the pre-flame reactions that are responsible for knocking on account of increased dilution. Also the maximum flame temperature attainable with the producer gas being lower compared to conventional fuels like methane, one could expect better knock resistivity.

1.3. Producer Gas Carburetor

A carburetor is a device that blends air and fuel for an internal combustion engine. The fuel in this case would be Producer Gas generated from biomass gasification systems after having been modified for some of its components. Producer gas consists of carbon monoxide and hydrogen with some amount carbon dioxide, methane and nitrogen. The blend of air and producer gas can then be fed into Direct Injection Engines for combustion purposes.

Mixing devices for gases used in gas engines generally referred to as carburetor, for mixing air and gaseous fuels are commonly attached to the intake manifold of an internal combustion engine. In gas carburetor the mixing of air and gaseous fuels needs to be in a proper ratio for a particular demand of the engine. In designing the producer gas carburetor, simplicity and ruggedness have always been considered as a basic requirement to achieve easy adjustment and reproducible performance. The effective area reduction of gas and air entry holes is considered by taking a suitable coefficient of discharge. The air and fuel flow is through orifices into the mixing chamber of the carburetor which enables proper mixing of air and fuel. The producer gas carburetor is being designed to have air and fuel flow at ambient conditions to be stoichiometry.

The producer gas carburetor is as shown in the Figure 3 has orifices placed at air and gas inlets such that the A/F ratio at ambient flow condition should be stoichiometry for a engine suction pressure of a 25 kWe engine. The amount of fuel flow inside the carburetor is controlled by a butterfly valve which is located prior to the air and fuel inlet orifices. The pressure balancing electronic controller drives suitably the butterfly valve with the help of a motor that brings the valves for a null pressure differential across the manifolds for the fuel and air attached upstream to the main engine manifold and works in suction pressures. If the differential pressure at both the carburetor manifolds are maintained at zero, with the manifolds tuned for their effective flow areas to match the ideal mixture condition, then the mixture flow what we get at engine intake manifold will be stoichiometry.

The Figure 1 shown above is the geometric model of the producer gas carburetor designed and analyzed for optimal pressure drop with good mixing ability. In order to overcome the problems associated with the use of zero pressure regulators and to maintain the stoichiometry A/F mixture, carburetor uses the orifices at both air and gas lines. Orifices are designed based on the mass flow rate of producer gas required for IC engine.

2. LITERATURE SURVEY

In the present situation emission affects a lot to the environment, so we need to reduce emission effect on the environment as much as possible. Klimstra J investigated that Current state of technological advances, it is recognized

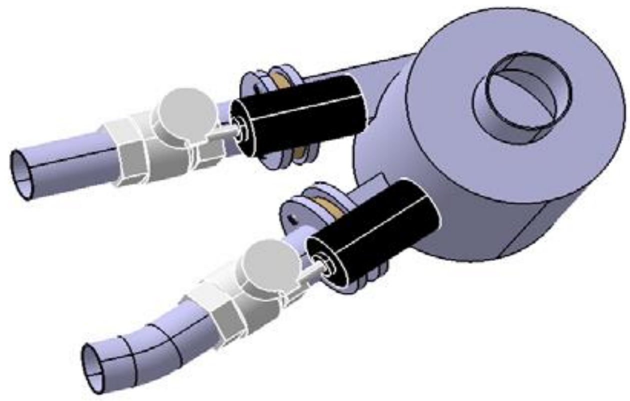


Figure 1

Experimental setup of PG Carburetor

that Biomass is one of the viable and sustainable renewable resources and new technologies emerging out of biomass based gasification systems find a significant role in bridging the energy crisis.

Versteeg et al. (1995) developed the advanced biomass gasification systems are known to generate producer gas as the combustible fuel that is clean enough to be used in Direct Injection gas engines. However in order to adapt standard gas engines few of its components need modifications before they are used in the biomass power plants. Since this area is an emerging one and the technology has not been disseminated to the scale of driving market, it is essential that specialized components that require modification need be studied. Carburetor is one of the important components in such Category and it is identified that additional research work is to be carried out in establishing a design procedure for this application. Sridhar et al. currently no Producer gas carburetors are being sold commercially. So the development of the carburetor which will fulfill all the requirements of low energy density fuels is a need of the time

Yoshishige Ohyama (1999) Studied how the Air/fuel ratio characteristic exert a large influence on exhaust emission and fuel economy in Internal Combustion engine. With increasing demand for high fuel efficiency and low emission, the need to supply the engine cylinders with a well defined mixture under all circumstances has become more essential for better engine performance. Carburetor is in general defined as devices where a flow induced pressure drop forces a fuel flow into the air stream. Air/fuel ratio characteristic exert a large influence on exhaust emission and fuel economy in Internal Combustion engine. Tung-Ching Tseng et al. (1999) with increasing demand for high fuel efficiency and low emission, the need to supply the engine cylinders with a well defined mixture under all circumstances has become more essential for better engine performance. An ideal carburetor would provide a mixture of appropriate air-fuel (A/F) ratio to the engine over its entire range of operation from no load to full load condition. To ensure proper performance, Carburetor should be reproducible and have unequivocal adjustment procedures. Further, Anil et al. (2006) investigated the Analysis of a Mixture Flow in a Producer Gas Carburetor using a CFD with a CFX. Versteeg et al. (1995) carried out study on introduction to CFD-The finite volume method.

In the recent times, gaseous fuels are gaining prominence as cleaner fuels for power generation via internal combustion engine route; the power generation package including both reciprocating engines and gas turbine machinery. Complete combustion with minimal emission is the key feature of gaseous fuels and this feature is currently being exploited the world-over for power generation purposes. Among the clean sources of fuel for power generation, natural gas has been exploited largely due to significant availability in specific locations. Similarly, there is also an impetus on using gas generated from industrial and municipal wastes, namely diluted natural gas – biogas and land-fill gas. As distinct from gas generation from biological/organic wastes by biological conversion process, which is limited to non-loganiaceous matter, the thermo chemical conversion route (also termed gasification) can process any solid organic matter. The range of biomass includes agro-residues like rice husk, sugarcane trash and bagasse in compact or briquetted form. The resultant gas known as 'Producer gas' can be used for fuelling a compression ignition (CI) engine in dual-fuel mode or a spark ignition (SI) engine in gas alone mode. Harnessing of energy from biomass via gasification route is not only proving to be economical but also environmentally benign friendly.

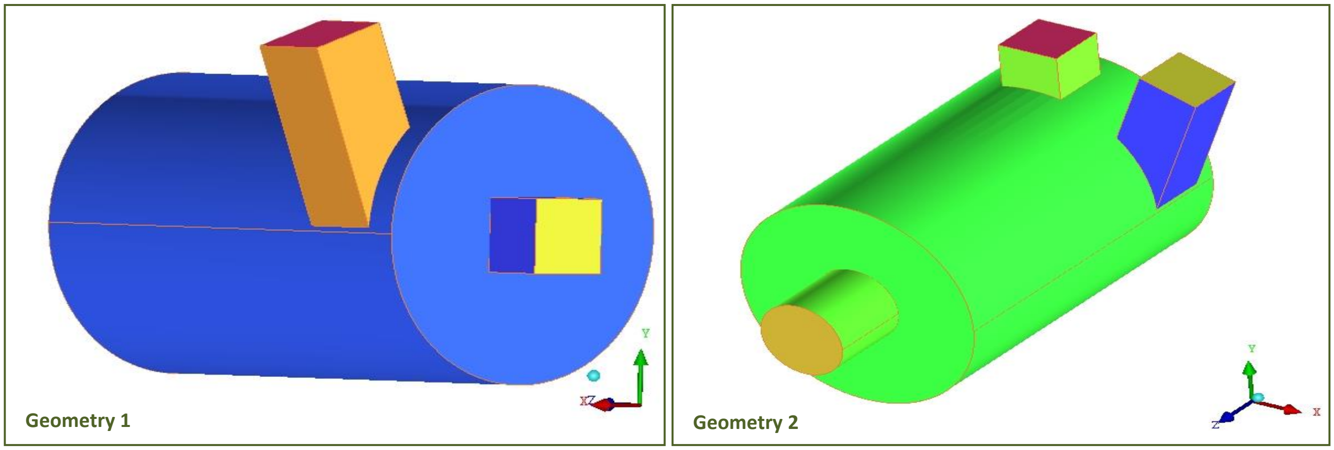
3. GEOMETRIC MODELING

The Figure 2 & Table 1 shows the design of the producer gas carburetor which is having different inlets for producer gas; simplicity and ruggedness have always been considered as a basic requirement to achieve easy adjustment and reproducible performance. The effective area reduction of gas and air entry holes is considered by taking a suitable coefficient of discharge. The air and fuel flow is through orifices into the mixing chamber of the carburetor which enables proper mixing of air and fuel. The producer gas carburetor is being designed to have air and fuel flow at ambient conditions to be stoichiometry. The producer gas carburetor has orifices placed at air and gas inlets such that the A/F ratio at ambient flow condition should be stoichiometry for an engine suction pressure of a 25 kWe engine. The amount of fuel flow inside the carburetor is controlled by a butterfly valve which is located prior to the air and fuel inlet orifices.

The pressure balancing electronic controller drives suitably the butterfly valve with the help of a motor that brings the valves for a null pressure differential across the manifolds for the fuel and air attached upstream to the main engine manifold and works in suction pressures. If the differential pressure at both the carburetor manifolds is maintained at zero, with the manifolds tuned for their effective flow areas to match the ideal mixture condition, then the mixture flow obtained at engine intake manifold will be stoichiometry. The

Table 1
Geometrical description

	Geometry-1	**Geometry-2**
Mixing section cylinder diameter	200 mm	200 mm
Mixing section cylinder	300 mm	300 mm
Outlet diameter	70 mm	70 mm
Outlet cylindrical section length	70 mm	70 mm
Air inlet duct cross-section	50 mm x 50 mm	50 mm x 50 mm
Air inlet duct length	127 mm	127 mm
Air inlet duct location	Tangential but at 20^0 angle *w. r. t.* the direction of the radial direction, at 45 mm from the end of the carburettor and 72 mm offset from the axis of the mixing section cylinder	Tangential but at 20^0 angle *w. r. t.* the direction of the radial direction, at 45 mm from the end of the carburettor and 72 mm offset from the axis of the mixing section cylinder
PG inlet duct cross-section	50 mm x 50 mm	50 mm x 50 mm
PG inlet duct length	40 mm	40mm
PG inlet duct location	Radially inward at 45 mm from the end of the carburettor	Axially inward on the circular cross-section at the end of the carburettor



Geometry 1

Geometry 2

Figure 2
Simplified models of PG Carburettor

geometric model of the producer gas carburetor designed and analyzed for optimal pressure drop with good mixing ability has been reported in the literature.

The air and producer gas passes through inlets of 50 mm x 50 mm. The air inlet is kept tangential to the mixing chamber whereas producer gas inlet is radial in one position and axially in another position to the mixing chamber. The outlet diameter is 35 mm based on the inputs for Reynolds number and velocity at the outlet assuming air at Standard Temperature Pressure. Air and producer gas enter into mixing chamber through an orifice of 28.0mm and 26.5mm diameter respectively. This will not be considered in the CFD analysis.

Grid Generation

Analysis will be done to determine the flow field, air/producer gas distribution for geometrical configurations at different air and fuel flow rates as reported in the experimental set-up. ANSYS ICEM CFD will be used for generating multi-block structured mesh for the geometries and ANSYS FLUENT will be used for doing the single phase multi species flow simulation.

Table 2

Material Properties

Component	Air (%)	Producer Gas (%)
Carbon dioxide	0.03	12.5
Carbon Monoxide	0.01	21
Hydrogen	0	21
Argon	0.86	0
Methane	0	3.5
Oxygen	21	0
Nitrogen	78	42
Total	100	100

Table 3

The Transport and 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 (W/m-K)	0.0240	0.0535

Domain Conditions

The CFD simulation will not include theorifices preceding the inlets but the geometry as described in Figure 1. A single phase, multispecies simulation will be carried out under atmospheric isothermal operating conditions for the geometry for the different set of air and PG boundary conditions. Turbulence will be modeled according to the k-e RNG turbulence model with wall functions for near wall treatment. A total of 7 transport equations will be solved: 1continuity, 3 momentum, 2 turbulence and 1 species equation for producer gas. The mass fraction of air being abundant will be calculated from the constraint relationship of (mass fractions of species) = 1.

4. MATERIAL PROPERTIES

Air ideal gas and Producer gas are considered to be different species with their averaged properties based on their individual constitution. The volume percentage in Tables 2 & 3 has been considered based on the experimental data available in the literature.

5. BOUNDARY CONDITIONS

The problem set-up has static pressure at the inlets and mass flow at outlets. As ANSYS FLUENT will be used in the present analysis, we will be using the experimental mass flow rates at the air and PG inlets and pressure outlet at the outlet boundary. For air inlet boundary condition mass and momentum, static pressure equivalent to domain reference pressure is set with flow condition being subsonic. The initial condition of flow through the air inlet with air ideal mass fraction as 1 is considered. The initial boundary condition for fuel inlet is same as the air inlet except for the flow of producer gas mass fraction being 1 at the inlet. The boundary condition for carburetor outlet is of different mass flow rate which is to be simulated is considered.

6. METHODOLOGY

To simulate the turbulence parameters, a standard k-ε model has been chosen with isothermal heat transfer condition at 300 K. we consider k-ε model with two new variables.

For the different A/F ratio and for thedifferent geometrical configurations, the massfraction distribution will be repo rted as mf_spread, defined as,

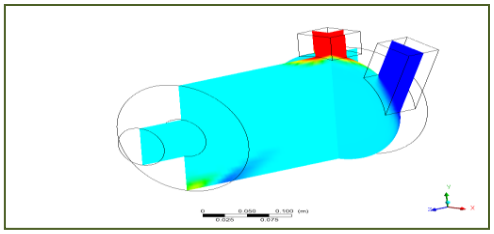


Figure 3.1

Mass Fraction

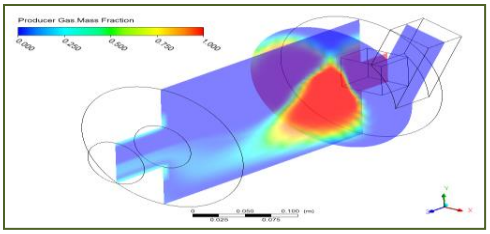


Figure 4.1

Mass Fraction

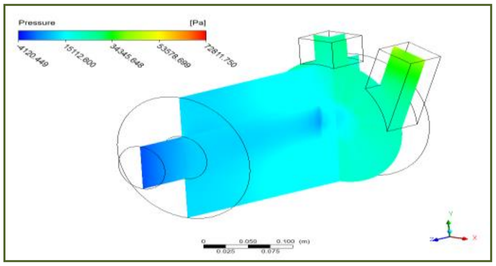


Figure 3.2

Pressure Contour

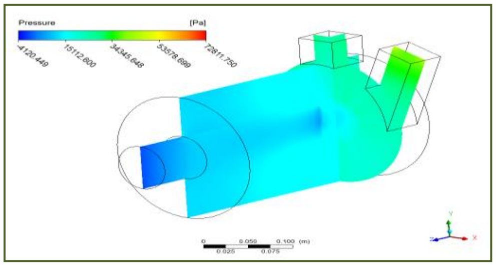


Figure 4.2

Pressure Contour

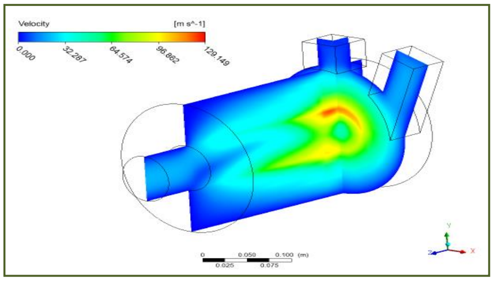


Figure 3.3

Velocity Contour

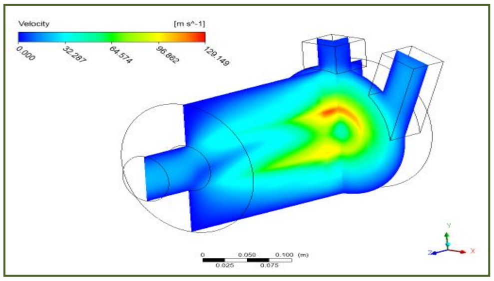


Figure 4.3

Velocity Contour

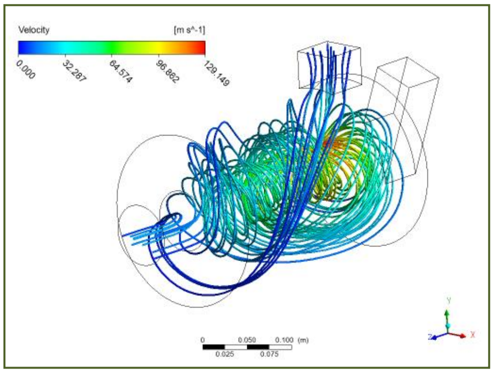


Figure 3.4

Velocity Pathlines

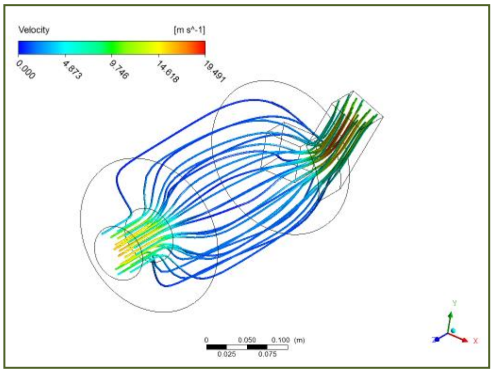


Figure 4.4

Velocity Pathlines

$$mf\ spread = \frac{2\sqrt{Ypgi - Ypg(avg)}}{n}$$

Where, Ypg,i = mass fraction of 'pg' at the i th face on the outlet surface

Ypg avg = average mass fraction of PG on the outlet surface

n = Number of faces on the outlet surface

The flow field will be described by plotting the following on 3 different planes for the geometric configurations at one design point only.

a. Velocity and pressure contours

b. Mass fraction plots for producer gas

7. RESULTS AND DISCUSSION

Air fuel Ratio : 2.931(**Air**-27.62,**PG**-9.423)

Geometry 1

Mass Fraction: It is observed that Mass fraction is high at air inlet and low at PG inlet and in medium range around 0.0005 at outlet. This is to be considered as a good enough for premixed combustion (Figure 3.1).

Pressure Contour: It is observed that pressure is around 40000Pa at inlet and very low at outlet around 5000Pa (Figure 3.2).

Velocity Contour: It is observed that velocity is very low at inlet and outlet and high in the middle section of the cylinder around 100m/sec (Figure 3.3).

Velocity pathlines (Figure 3.4)

Geometry 2

Mass Fraction: It is observed that Mass fraction is high at air inlet and low at PG inlet and in medium range around 0.00542957 at outlet. This is to be considered as a good enough for premixed combustion (Figure 4.1).

Pressure Contour: It is observed that pressure is around 20000Pa at inlet and very low at outlet around 3000Pa (Figure 4.2).

Velocity Contour: It is observed that velocity is very low at inlet and outlet and high in the middle section of the cylinder around 100m/sec (Figure 4.3).

Velocity pathlines (Figure 4.4)

From the above figures it is observed that Mass fraction is high at air inlet and low at PG inlet. PG and air fairly well making its mass fraction is more in gemotry 2 than the geometry 1. This mass fraction is to be considered as a good enough for premixed combustion. This proper mixed fuel and air will enter into the combustion chamber. Because of this there will be a complete combustion and the exhaust gas produces low emissions.

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Turbulent model based on k-ε theory with a RANS code has been used for the CFD predictions of the producer gas mass fraction and the carburetor performance has been evaluated for two different geometries leading to bringing out of an optimal design of the PG carburetor that is used for prototype testing and real–time testing. It is observed that mass fraction is considered to be good for premixed combustion for both geometries but geometry 2 is having mass fractiion more than geometry 1 hence geometry 1 is more preferable than the geometry 2, so there will be a proper mixing of air and fuel. This well mixed fuel will enter into the combustion chamber and there will be a complete combustion. Because of properties of producer gas fuel and the well mixing of air and fuel, the emission produced will be low at the exhaust.

8. CONCLUSION

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