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Numerical and Experimental Modeling of Producer Gas Carburettor

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Abstract

Currently there has been no Producer gas carburettors sold commercially. Some of the concepts evolved have not been optimized and are not standardized as well. In this view, development of an optimized carburettor for producer gas application addressing the low energy density of the delivered mixture is need of the time. Design of a carburettor for producer gas application with special reference for reduced loss of pressure is taken up to generate the optimal fuel–air mixture to meet different load conditions of the engine as well as for varying operating conditions of producer gas reactor. A specially designed producer gas carburettor is comprehensively analyzed for its mixing performance and response with a CFD modeling. The model is made up of a mixing chamber that has the essential orifices for air and fuel (producer gas) inlets to generate stable stoichiometric mixture nearer to ambient conditions. The CFD simulations are carried out followed with experimental studies under engine simulation conditions using pressure controlling system to validate the analysis. The results show a consistency in the experimental data and the modeling has provided a good insight into the flow details and has paved way in optimization of geometrical design to get a good mixing efficiency.

Keywords: computational fluid dynamics, producer gas, carburettor, air/fuel ratio, turbulence

1. Introduction

In the 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. 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. [3]. the work presented here is an effort in this regard.

Air/fuel ratio characteristic exert a large influence on exhaust emission and fuel economy in Internal Combustion engine[5]. 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. Carburettors are in general defined as devices where a flow induced pressure drop forces a fuel flow into the air stream [1]. An ideal carburettor 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, Carburettors should be reproducible and have unequivocal adjustment procedures.

CFD software used for cold flow analysis is CFX 10.The k-ε turbulence model is most commonly used and is considered to be the best model between computational time and precision [2]. The geometric model is built using Ansys workbench.

2. Producer Gas Carburetor

Mixing devices for gases used in gas engines generally referred to as carburettor, for mixing air and gaseous fuels are commonly attached to the intake manifold of an internal combustion engine. In gas carburettor 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 carburettor, 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 carburettor which enables proper mixing of air and fuel. The producer gas carburettor is being designed to have air and fuel flow at ambient conditions to be stoichiometry. The producer gas carburettor is as shown in the Fig.1 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 carburettor 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 carburettor 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 Fig.1 shown below is the geometric model of the producer gas carburettor 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, carburettor 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. Fig.2 shows the orifice meter for air and gas control.

3. Experimentations and CFD Simulations

Fig.3 shows the assembled view of the carburettor and schematic view of the Test-Rig setup as shown in Fig.4. Engine simulating experimental set up consists of two blowers which are fixing at suction and forced mode. The setup so as to achieve nearly producer gas engine working conditions.

The figure 5 shows the pressure controller timing diagram indicating, when there is a rise in pressure difference between the two inlets of the carburettor, due to changes in the load, there is a corresponding change in the input voltage from the pressure sensor to the pressure controller circuit. The ECM takes corrective action by actuating the motors thereby valves connected to the inlets thereby regulating zero pressure difference across the two inlets, this in turn maintains the stoichiometry. The potentiometer output changes accordingly and the data is acquired using the DAQ system.

Table 1. Experimental Engine Simulation data.

Sl no	ΔP across venturi meter (air side) g/s	ΔP across venturi meter (PG side) g/s	ΔP across Air Orifice in mm of water column	ΔP across PG Orifice in mm of water column	Absolute pressure (carburettor outlet) mm of water column	Air flow rate g/s	Fuel flow rate g/s	A/F ratio
1	68	10	25	6	102	27.62	9.423	2.931
2	68	20	25	10	102	27.62	13.32	2.074
3	68	30	25	13	99	27.62	16.32	1.692
4	68	40	25	19	99	27.62	18.85	1.465
5	68	50	25	22	97	27.62	21.07	1.311
6	68	60	25	25	95	27.62	23.08	1.196
7	68	70	25	30	95	27.62	24.93	1.108

4. CFD Analysis

4.1. Problem definition

CFD Simulations are carried out on the producer gas carburettor geometric models as shown in Fig. 6. The air and producer gas passes through inlets of 50mm X 50mm. The air inlet is kept tangential to the mixing chamber whereas producer gas inlet is radial to the mixing chamber, air and producer gas enter into mixing chamber through an orifice of 28.0mm and 26.5mm diameter respectively. The structured grid model shown in Fig.7 used to simulate the flow analysis in a carburettor with mesh density of around 55936 computational nodes.

4.3. Boundary and Initial Conditions

The flow domain considered for simulation the carburettor mixing chamber with steady state flow. Here for simplicity of analysis a single gas (carburettor gas) entity is considered having air ideal gas and producer gas. The relative pressure of the carburettor domain is 1 atmosphere with non buoyancy condition. 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 carburettor outlet is of different mass flow rate which is to be simulated is considered.

A 3 Dimensional RANS code having unwinding implicit scheme and k–ε approach for turbulence is used for obtaining numerical solution. The Equations are solved for steady incompressible flow. The boundary conditions and initial conditions used include (a) no slip and adiabatic walls; (b) At inlet and outlet ports, pressure and mass flow rate respectively.

4.4. Computational Approach

Turbulence consists of fluctuations in the flow field in time and space. It is a complex process, mainly because it is three dimensional, unsteady and consists of many scales. It can have a significant effect on the characteristics of the flow. Turbulence occurs when the inertia forces in the fluid become significant compared to viscous forces, and is characterized by a high Reynolds Number. The k-ε model of turbulence is widely chosen for fluid flow analysis. k is the turbulence kinetic energy and is defined as the variance of the fluctuations in velocity. ε is the turbulence eddy dissipation (the rate at which the velocity fluctuations dissipate).

To simulate the turbulence parameters, a standard k-ε model has been chosen with isothermal heat transfer condition at 300 K. The Solver uses k-ε model with two new variables and the continuity equation is then.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho U) = 0 \qquad \textit{(i)}$$

And the momentum equation becomes. [6]

$$\frac{\partial \rho U}{\partial t} + \nabla \cdot (\rho U \otimes U) - \nabla \cdot (\mu_{eff} \nabla U) = \nabla p' + \nabla \cdot (\mu_{eff} \nabla U)^{T} + B \qquad \textit{(ii)}$$

The flow–solver CFX-10 used for the analysis uses the differential transport equation for the turbulence kinetic energy and turbulence dissipation for analysis.

The equation for kinetic energy K is given by

$$\frac{\partial (\rho \kappa)}{\partial t} + \nabla \cdot (\rho U k) = \nabla \cdot \left[\left(\mu + \frac{\mu_t}{\sigma k} \right) \nabla k \right] + P_k - \rho \varepsilon \qquad \textit{(iii)}$$

The equation for ε without compressibility is given by.

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \nabla \bullet (\rho U \varepsilon) = \nabla \bullet \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \nabla \varepsilon \right] + \frac{\varepsilon}{K} \left(C_{\varepsilon 1} P_K - C_{\varepsilon 2} \rho \varepsilon \right) \qquad (iv)$$

5. CFD Results

In this section, contour plots of producer gas mass fraction, various velocity vector plots and velocity streamline plots, across different planes is presented.

5.1. Producer gas and air flow mixture analysis

The Fig.8 shows the producer gas mass fraction contour plot at different cross sectional plane. From the analysis, it is seen that the producer gas carburettor mixes producer gas and air fairly well making its mass fraction variation nearly 0.004 that is known to be good enough for premixed combustion. The velocity at outlet is below 10m/s, Re 35055 and pressure drop across the carburettor is 116 Pa.

6. Conclusion

Three dimensional CFD computations on producer gas carburettor made have been able to capture the detailed functional features of fluid flow in the carburettor configurations considered and are found to be consistent with the experimental work done with simulations for engine operating conditions. 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 carburettor performance has been evaluated leading to bringing out of an optimal design of the PG carburettor that is used for prototype testing and real–time testing. The experimental results compared with CFD results indicate that the flow patterns captured by the CFD analysis are close to the patterns captured from the experimental results, implying that verification for the CFD analysis is comprehensive enough having consistency among the two studies.

At present stage newly built differential pressure carburetor is tested under engine simulating conditions and results found good in comparison with CFD results. Since unavailability of the engine of 25 kWe at present stage, the experimentation work regarding implementation of pressure sensing based gas carburetor can be extended to the run-time measurement of air fuel ratio, load and speed variations in real engine conditions.

Once the engine of required capacity is made available, test runs on the engine is necessary to make the newly developed technology to be fool-proof before actually implementing the pressure sensing based producer gas carburetor for industrial applications. This will form the major part of future work to be carried out.

7. References

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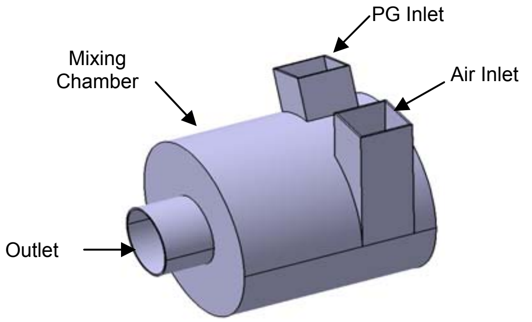
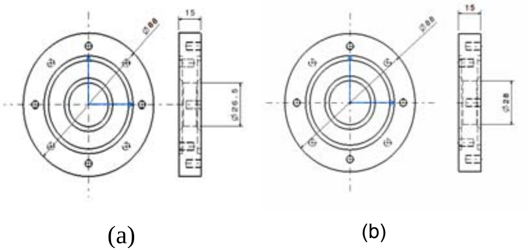


Fig.1 3-D Model of producer gas carburetor.



(a) (b)

Fig.2 Flow Control Orifices for Producer Gas Carburetor (a) Fuel control (b) Air control

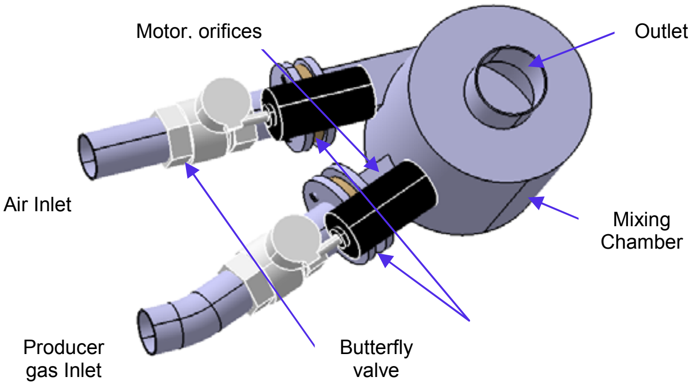


Fig.3 Assembled view of the setup.

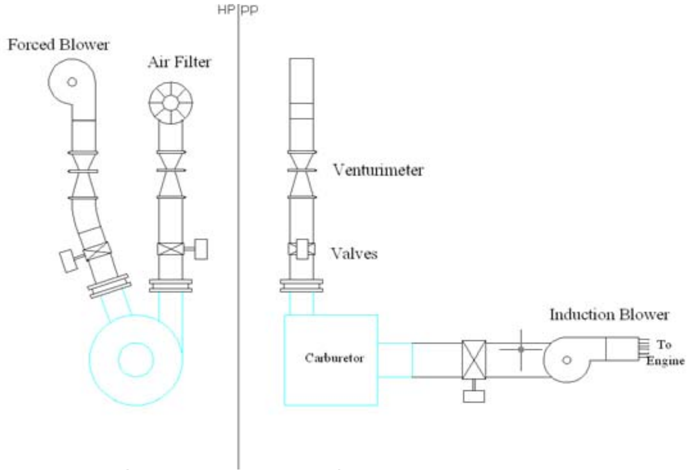


Fig.4 Schematic view of the Test Rig setup

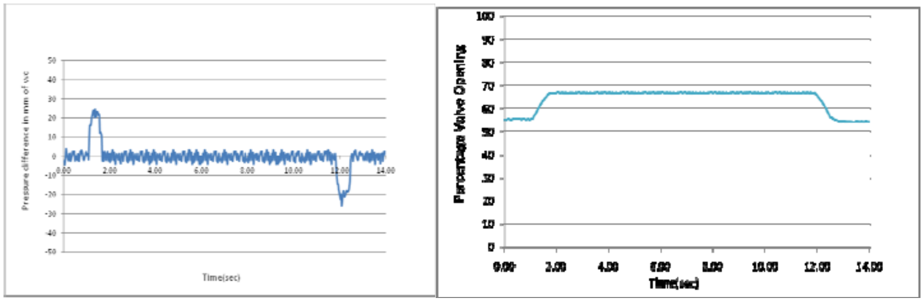
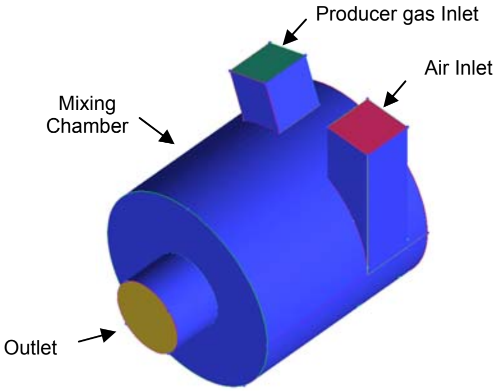


Fig.5 Pressure controller timing diagram.



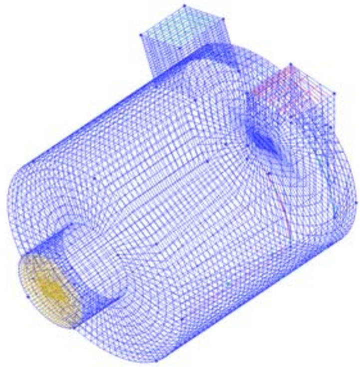
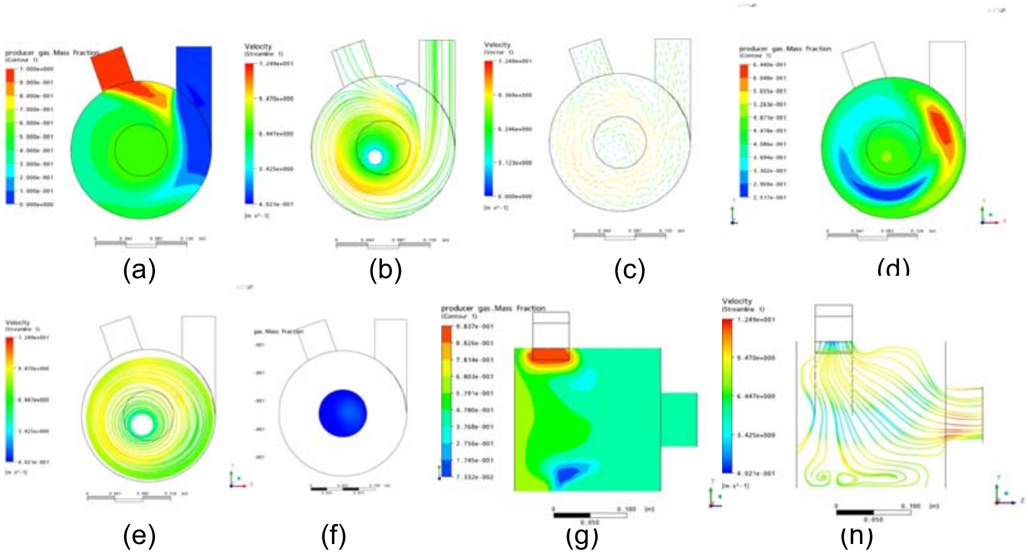


Fig.6 Geometric model of Producer Gas

Fig.7 Structured Mesh Model



(a) (b) (c) (d)

(e) (f) (g) (n)

Fig.8 CFD simulation plots at different cross sectional plane.