Design and Simulation of a Carburattor to Run an Otto Engine on Producer Gas

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Abstract— **This study presents the design and simulation of a carburetor optimized for internal combustion engines running on producer gas, a renewable fuel derived from biomass. Due to the lower energy density of producer gas compared to conventional fuels, achieving an optimal air-fuel ratio is critical for efficient combustion. Several carburetor models were developed and simulated using ANSYS to assess their mixing performance and ability to maintain the required air-fuel ratio under varying conditions. The simulations highlighted challenges in achieving a homogeneous mixture, with early models exhibiting poor mixing and safety risks, such as the potential for backfire due to inadequate pressure relief mechanisms. To address these issues, successive models incorporated design improvements and optimized nozzle configurations, which significantly enhanced the mixing quality. The final model demonstrated a substantial improvement in the uniformity of the air-fuel mixture, ensuring stable engine operation. These findings underline the importance of precise control over the mixing process in carburetor design for alternative fuels like producer gas. The results provide a foundation for further refinement and practical implementation of this technology, contributing to the development of more sustainable energy solutions.**

Keywords— producer gas, CFD Simulation, gas carburetor, pre-mix combustion

I. INTRODUCTION

An internal combustion engine is any engine that uses the explosive combustion of fuel to push a piston within a cylinder. The different types of fuel commonly used for combustion engines are gasoline, diesel, and kerosene. Many people claimed the invention of the internal combustion engine in the 1860s, but only one has a patent on the four-stroke operating sequence. In 1867, Nikolaus August Otto, a German engineer, developed the four-stroke "Otto" cycle, which is widely used in transportation even today [1]. The Diesel Engine came about in 1892 by another German engineer, Rudolph Diesel. The Diesel engine is designed heavier and more powerful than gasoline engines and utilizes oil as fuel.

Since petroleum products were available and inexpensive in the 19th century, these kinds of IC engines were very common and popular in the transportation and power generation sectors. Fossil fuels were the major energy source and they can be burned to produce a significant amount of energy per unit mass (In the range of 30 $MJkg^{-1}$ – 48 $MJkg^{-1}$) [2]. Most of the power plants are based on fossil fuels in the present. The question here is whether fossil fuels running out of the world at a high rate due to inefficient consumption. The rate at which the world consumes fossil fuels is not standing still, it keeps increasing with the world's population increase. Fossil fuels will, therefore, run out earlier than expected.

With the renewed interest in biomass energy, biomass-based technologies are gaining prominence not only in the rural energy sector but also in industrial power plants. Biomass is emerging as a leading source of renewable energy due to several advantages: it utilizes agricultural waste, is available in large quantities, supports eco-friendly gasification processes, and produces gasification outputs that can be stored as fuel.

Producer gas from biomass gasification is expected to contribute to a greater energy mix in the future. Therefore, the effect of producer gas on engine performance is of great interest. Presently, the use of 100% producer gas in spark ignition (SI) engines was not successful, because producer gas has low energy density [3]. Increasing energy efficiency and the use of alternative fuels in place of fossil fuels are the main challenges within this project. As a gaseous fuel, producer gas is a better option as an environment-friendly fuel. With the help and knowledge of recent discoveries and research, the project is headed to the design and simulation of a carburetor to run a gasoline engine with producer gas.

II. LITERATURE REVIEW

A. Importance of producer gas

The use of efficient renewable energy technologies was very popular over the past several years. Those technologies are receiving increasing attention from government, industry, and consumers. Wind energy, hydro energy, solar energy, and biomass energy are some of the renewable energy technologies.

Although the consumption of biomass-based energy is high, the efficiency of biomass systems is not at a satisfactory level [4]. Throughout the known history, wood has been used as a source of heat by burning the wood directly. But in the case of burning wood, we lose about 67% of its energy in the environment with smoke [5]. The laws that govern combustion processes also apply to gasification. Therefore, the purpose of gasification is the almost complete transformation of these components into a gaseous form so that only the ashes and inert materials keep on [6]. Producer gas is an example of using biomass efficiently. It is needed to increase the efficiency of existing energy generation processes due to the scarcity of energy sources.

B. *Role of gasification in biomass conversion*

Biomass is renewable energy with many positive features. The technology of biomass gasification gives a profitable choice of power generation for a wide variety of applications including distributed power generation [7]. Biomass contains mostly organic matter & waste materials from plants and animals that are not used for food and feed but can be used as a fuel. Gasification is a thermochemical process that converts biomass or fossil fuel-based carbonaceous materials into CO, H_2 & CO_2. This is accomplished by reacting the materials at high temperatures (>700^0C) without complete combustion and with a controlled amount of O_2 [8]. The air-fuel ratio should be maintained below the stoichiometric ratio. In case complete combustion happens, the results will be CO_2 & H_2O which are not combustible gases.

C. *Content of producer gas*

Biomass-based producer gas generally contains 18-20% each of H_2 and CO, 2% of CH_4, and other inert gases such as CO_2 and N_2 [9]. In order to that, there are some hydrocarbons such as ethylene (C_2H_2), ethane (C_2H_6), and a small amount of tar and ash [10]. The lower calorific value of producer gas is approximately between 4.5 and 4.9 MJ/kg and the stoichiometric air-fuel ratio is present at 1.25 ±0.05 on a mass basis [9]. When compared with gasoline (54 MJ/kg), producer gas is a kind of low-energy-density fuel. Some of the important specific properties of air and producer gas are shown in Table I. These data can be used to analyze the mixing of air and producer gas through and intake manifolds of dissimilar geometrics using computational fluid dynamics (CFD).

TABLE I. SPECIFIC PROPERTIES OF AIR AND PRODUCER GAS [11]

Property	Air	Producer Gas
Density (kg/m^3)	1.175	0.978
Viscosity (Pas)	1.179×10^{-5}	1.452×10^{-5}
Specific Heat (J/kg K)	1005.148	3838.358
Thermal Conductivity (kW m/K)	0.0248	0.0535

D. *Properties of producer gas*

Comparing the properties of producer gas with those of pure gases is an effective method for identifying the unique qualities and behaviors of producer gas. Key data on producer gas, in comparison with pure gases, is presented in Table II.

TABLE II. COMPARISON OF PRODUCER GAS AND PURE COMBUSTIBLE GASES [12]

Fuel + Air	Fuel LCV, MJ/kg	Air/Fuel @ (Φ =1)	Mixture, MJ/kg	Φ, Limit		S_L (Limit), cm/s		S_L Φ =1, cm/s	Peak Flame Temp, K	Product/ Reactant Mole Ratio
				Lean	Rich	Lean	Rich			
H_2	121	34.4	3.41	0.01	7.17	65	75	270	2400	0.67
CO	10.2	2.46	2.92	0.34	6.80	12	23	45	2400	0.67
CH_4	50.2	17.2	2.76	0.54	1.69	2.5	14	35	2210	1.00
C_3H_8	46.5	15.6	2.80	0.52	2.26	-	-	44	2250	1.17
C_4H_{10}	45.5	15.4	2.77	0.59	2.63	-	-	44	2250	1.20
PG	5.00	1.35	2.12	0.47 a	1.60 b	10.3	12	50 c	1800 d	0.87

When comparing producer gas with methane is more important with respect to the operation of the internal combustion engine [12]. The reason why is most of the engines operating on gaseous fuels are very close to pure methane (natural gas) or diluted methane (biogas, landfill gas) [12]. The fuel-air mass equivalence ratio at the flammability limits compares closely for both gases, but the laminar burning velocity for producer gas at the lean limits is much higher. Due to the presence of H_2, the laminar burning velocity for producer gas (at 0.1MPa, 300K) is about 0.5ms^{-1} which is approximately 30% higher than methane. This is caused by lower advancement in the ignition timing for the engine based on producer gas fuel [12].

Although producer gas can be used for IC engine operations, it has largely been left unexploited due to additional perceptions which are auto-ignition tendency at higher compression ratio and large de-rating in power due to lower calorific value. After re-examining those perceptions, it was discovered that due to the presence of hydrogen, laminar burning velocity being high, and it might reduce the tendency for the knock. Also, the presence of CO_2 and N_2 might suppress the pre-flame reactions that are caused by knocking on account of increased dilution. In order to that, there is a general perception that producer gas being a low energy density fuel, the extent of de-rating in power would be large when compared to high energy density fuels like natural gas or liquefied petroleum gas [12].

III. METHODOLOGY

In this research, it is expected to simulate the mixing capabilities of producer gas and air, in order to obtain the correct air-fuel ratio. As an initial stage commercially available IC engine was selected and simulation was done for the selected RPM value.

A. *Selection of an Engine*

The research deals with the use of producer gas efficiently for power generation. Engine capacity is a measurement of how large the space, is where the piston operates. A larger capacity means the piston is able to push more air and fuel, in this research, producer gas as fuel. It usually follows that if the capacity is bigger, with more power you can expect the engine to produce [13]. Fig. 1 shows the selected engine and relevant specifications are as follows:

Fig. 1. Single-cylinder, four-stroke engine (Model: 156FMI-2Z2)

Displacement: 124.1ml
Compression ratio: 9.0:1
Primary reduction: 4.055
Bore*Stroke: 56.5mm*49.5mm
Max. Net Power & Rotating Speed:7.2kW/9000r/min
Rated Power & Rotating Speed:7.0kW/9000r/min
Max Torque & Rotating Speed:8.3N.m/7500r/min
Min Fuel Consumption: ≤ 367g/kWh
Idling Speed: 1500r/min
Ignition: CDI

B. *Identification of design specifications*

The basic requirement of a carburetor is its ability to maintain the necessary air-to-fuel ratio under varying load or throttle conditions. Additionally, it should ensure smooth operation with minimal pressure loss. Another critical function is to shut off the fuel supply in case of engine tripping or shutdown. Since the air-to-fuel ratio is a fixed value for any given fuel and air, the required rate of mixed air-fuel is also considered fixed, based on simulations performed for the selected RPM value.

Another important factor is the mixing capability and quality of the air-fuel mixture. The carburetor should provide a homogeneous mixture at the end of the mixing process. To assess the mixing capability, three different models were developed, and the mixture at their outlets was evaluated. Afterward, the model that produced the best mixture was selected, and simulations continued to achieve the required air-to-fuel ratio.

C. *Air-to-fuel ratio calculation*

The main content of producer gas is shown in Table III.

TABLE III. CONTENT OF PRODUCER GAS [14]

Component	Volume Percentage (%)	Mass Percentage (%)
H_2	20	1.65
CO	20	23.17
CH_4	2	1.32
CO_2	10	18.21
N_2	48	55.62

The flammable gases in this case are H_2, CO, and CH_4. The required O_2 mass for the complete combustion of each flammable component has been calculated, and the final air-fuel ratio was determined to be 1.36 for the given composition. This ratio may vary depending on the volume content of each gas component.

D. *Governing Equations*

The CFD simulations conducted in ANSYS Fluent were based on fundamental fluid dynamics equations to model the flow and mixing of producer gas and air. The primary governing equations include:

Continuity Equation: Ensures mass conservation, expressed as equation (1) for incompressible flows.

$$\nabla \cdot \mathrm{v} = 0 \tag{1}$$

Momentum Equations (Navier-Stokes): Govern the conservation of momentum, given by:

$$\rho\left(\frac{\partial \mathrm{v}}{\partial t} + (\mathrm{v} \cdot \nabla)\mathrm{v}\right) = -\nabla p + \mu \nabla^2 \mathrm{v} + f \tag{2}$$

These equations are essential for predicting velocity and pressure fields.

Energy Equation: Although temperature effects were assumed constant, the energy equation can be expressed as:

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\mathrm{v}(\rho E + p)) = \nabla \cdot (k \nabla T) + S \tag{3}$$

Turbulence Modeling: The $k-\epsilon$ model was employed to account for turbulence effects, using two transport equations for turbulence kinetic energy (k) and dissipation rate (ϵ). These equations provided the framework for accurately simulating the mixing process in the carburetor design.

E. *Simulations and Developments*

Model 01

A simple structure for air and fuel mixing with a mechanism to supply the required rate of fuel mixture by automatic means. 3 types were formulated by changing the position of inlet and outlet ports and some slight changes in the design as shown in Fig. 2. Simulations were done for all the 3 types. The requirement was to check the Producer gas and air, mixing under varying flow rates to gain the correct air-fuel ratio. The applicability of those models was checked by visualizing mass fractions of Producer gas at the mixture outlet. Some of the simulated results are shown in Table IV.

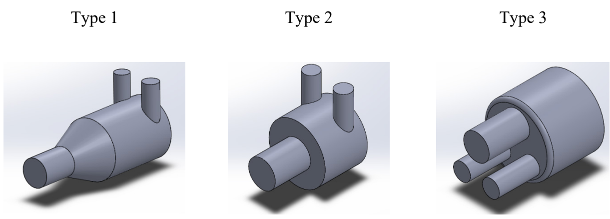
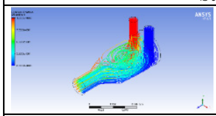
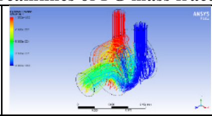
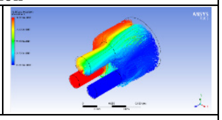
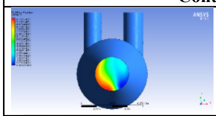
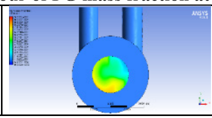
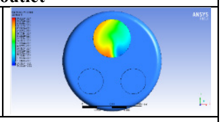
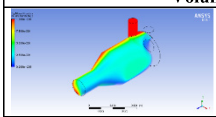
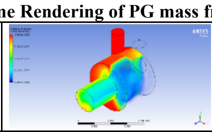
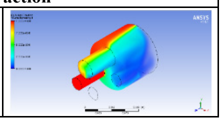


Fig. 2. Model 01 types

TABLE IV. SIMULATED RESULTS FOR MODEL 01(TYPE 01,02 & 03)

Model 01-Type 01	Model 01-Type 02	Model 01-Type 03
Mesh Quality Parameters		
Nodes: 56275 *Elements: 307556*	*Nodes: 58345* *Elements: 318028*	*Nodes: 57782* *Elements: 314863*
Streamlines of PG mass fraction		
		
Contour of PG mass fraction at outlet		
		
Volume Rendering of PG mass fraction		
		

According to the above-simulated results, types 2 & 3 were suitable for the final design but type 2 was the best-suited design. The reason was that the Producer Gas (PG) mass fraction spreads more uniformly throughout the Gas-mixture outlet area than the other two designs (Refer to the contour of the PG mass Fraction at the outlet in Table IV).

In addition to the simulation results, practical considerations revealed that Model 01 was a failed design due to several safety and performance issues. These include the risk of explosion in the mixing chamber during a backfire, as there was no pressure relief mechanism in place. Additionally, a considerable amount of mixed air and fuel was present in the chamber at any given moment, posing further risks. Furthermore, the prototype did not achieve the required level of fuel mixing, making the design inadequate.

Model 02

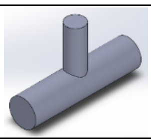
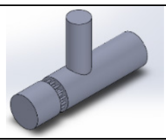
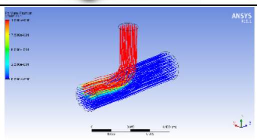
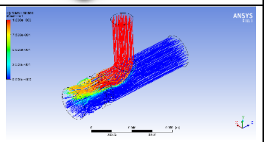
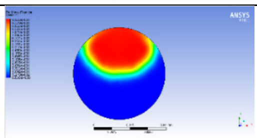
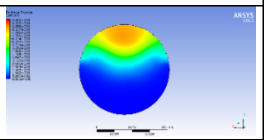
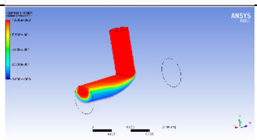
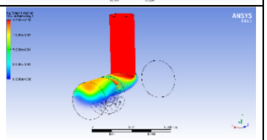
As model 01 was not successful, model 02 was created (Fig. 3). There are no automatic means for mixing the fuel with air, and the required mixture is obtained by using 2 flow control valves placed in inlets of air and producer gas. To reduce the pre-mixed air volume model 02 was designed.

Type 1 Type 2

Fig. 3. Model 02 types

The expected level of mixing was not achieved, as producer gas and air could still be seen separately at the tube outlet. To improve mixing, turbulence in the flow needs to be maximized. In Type 02 of Model 02, a baffle plate was introduced, which significantly enhanced the mixing compared to Type 01 of Model 02.

TABLE V. SIMULATED RESULTS FOR MODEL 02 TYPES

	Model 02 -Type 01	**Model 02 -Type 02**
Basic Design		
Streamlines of PG mass fraction		
Contour of PG mass fraction at outlet		
Volume Rendering of PG mass fraction		

Model 03

This model is the same as the Bunsen burner mechanism. There are 2 ports for the air inlet and one for producer gas inlet. Mixing happens automatically with the change of flow of producer gas.

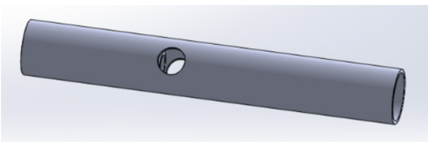
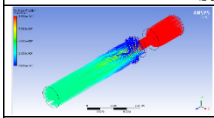
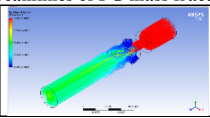
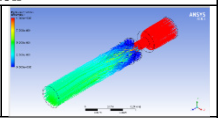
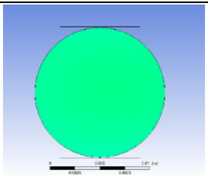
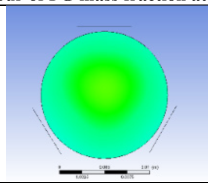
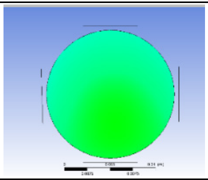
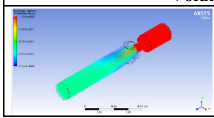
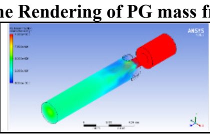
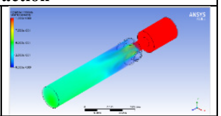


Fig. 4. Model 03

When the producer gas is supplied through the inlet, due to the nozzle effect air automatically flows inside the tube. The simulation was performed to decide design parameters to obtain the required air-fuel ratio. The first investigation was to select the number of holes for the air inlet. Basically, 3 prototypes (each including holes 2,3, and 4 respectively) were selected and simulation was done using ANSYS 18.1 to identify the mixing capabilities. Detailed analysis is shown in Table VI.

According to the results in Table VI, all the types were appropriate for the final design but type 1 was the best-suited design. The reason was that the PG mass fraction spreads uniformly throughout the gas-mixture outlet area than the other two designs (Refer to the contour of the PG mass Fraction at the outlet in Table VI).

TABLE VI. DETAILED ANALYSIS FOR 3 TYPES IN MODEL 03

Model 03-Type 01	**Model 03-Type 02**	**Model 03-Type 03**
Mesh Quality Parameters		
Nodes: 68143 *Elements: 360614*	*Nodes: 71517* *Elements: 380228*	*Nodes:74834* *Elements:398627*
Streamlines of PG mass fraction		
		
Contour of PG mass fraction at outlet		
		
Volume Rendering of PG mass fraction		
		

After selecting a two-holes model, parametric simulations were done to select the most suitable model. Here the selected nozzle was modeled using ANSYS 18.1 Design Modeler and followed the same basic procedure same in simulating model 01 and model 02. The aim was to identify the relationship between the geometrical dimensions and outlet producer gas mass fraction. To make this process easier some parameters were kept constant (Refer to Table VII).

Geometry and boundary conditions

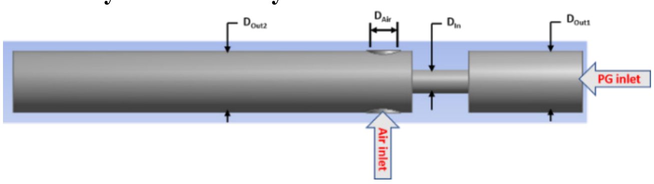


Fig. 5. Model 03 detail design

TABLE VII. VARIABLE AND CONSTANT PARAMETERS USED FOR SIMULATIONS IN MODEL 03

Variable Parameters		**Constants Parameters**		
D_{In}	Producer gas nozzle diameter	D_{Out1}	10mm	PG inlet diameter
D_{Air}	Air inlet diameter	D_{Out2}	10mm	Mixture outlet diameter
V_{INPG}	PG inlet Velocity			

Using variables as shown in Table VIII and Table IX, the 3D fluid domain was created using ANSYS 18.1 Design modeler. For those parameters, two data sets were introduced.

TABLE VIII. CONSTANT VELOCITY MODELS

Model No	D_{in} (mm)	D_{Air} (mm)	V_{inPG} (ms^{-1})
1	2	2	1
2	2	3	1
3	2	4	1
4	2	5	1
5	2	6	1
6	3	2	1
7	3	3	1
8	3	4	1
9	3	5	1
10	3	6	1
11	4	2	1
12	4	3	1
13	4	4	1
14	4	5	1
15	4	6	1
16	5	2	1
17	5	3	1
18	5	4	1
19	5	5	1
20	5	6	1

TABLE IX. CONSTANT DIAMETER MODELS

Model No	D_{in} (mm)	D_{Air} (mm)	V_{inPG} (ms^{-1})
1	4	4	1
2	4	4	0.9
3	4	4	0.8
4	4	4	0.7
5	4	4	0.6
6	4	4	0.5
7	4	4	0.4
8	4	4	0.3
9	4	4	0.2
10	4	4	0.1

Mesh & mesh quality

The mesh was structured with the Hex-dominant method in order to create the best mesh quality in all the parts of the domain since it is undisturbed with any geometry (Refer Fig. 6). A surface sizing with a comparatively smaller element size was added to comply with the complicated boundary conditions that would be created near the nozzle area as shown in Fig. 7.

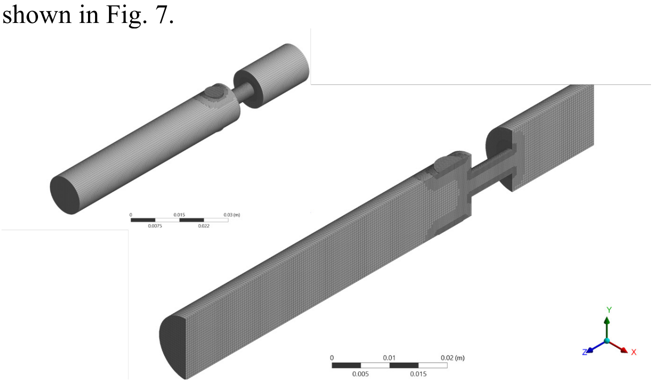


Fig. 6. Hexahedral computational mesh

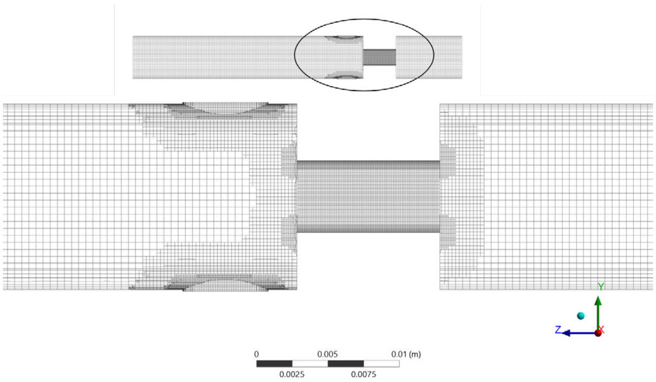


Fig. 7. Refined mesh near the neck

Mainly Skewness, Element Quality, and Aspect Ratio were considered when refining the mesh. Respective values for the final design are shown in Table X. According to those parameters, it could be guaranteed that the selected mesh was suitable for further simulation processes.

TABLE X. SKEWNESS, ELEMENT QUALITY AND ASPECT RATIO OF THE FINAL REFINED MESH

Mesh Metric	Skewness	Element Quality	Aspect Ratio
Min	1.305×10^{-10}	0.4811	1.0182
Max	0.7592	0.9998	5.8220
Average	4.414×10^{-2}	0.9802	1.1902
Standard Deviation	0.1145	5.378×10^{-2}	0.4849

Problem domain

Producer gas is supplied through the PG inlet at a constant velocity. Due to the effect of the nozzle, atmospheric air is drawn into the hollow tube through two holes and mixed with the producer gas. The average mass fraction of the producer gas at the mixture outlet and the outlet velocity of the mixture were measured as part of the results. The assumptions made in the simulations are listed below:

- The properties of producer gas and atmospheric air are constant throughout the simulation.
- There is no chemical reaction between the producer gas and atmospheric air.
- The temperature of the system remains constant.
- There is no backpressure at the gas mixture outlet.
- Gravitational forces can be neglected.

The setup of boundary conditions and the solution methods used in the simulation are summarized in Table XI.

TABLE XI. SETUP, BOUNDARY CONDITIONS, AND SOLUTION METHODS

Solver	Type- *Pressure Based* Time- *Steady* Velocity Formulation- *Absolute*
Model	Energy solver- *On* Viscous Model- *Standard k-epsilon with standard wall function* Species – *Species Transport*
Material	Fluid 1- *Air (Ideal gas properties)* Fluid 2 - *Producer Gas*
Cell Zone	Air Volume – *Air and Producer gas mixture*
Boundary Conditions	PG Inlet – *Velocity inlet, Constant velocity, PG @300K* Air Inlet – *Pressure inlet (Atmospheric) @300K* Mixture Outlet- *Pressure Outlet (Atmospheric)* Tube Walls - *Stationery and no-slip adiabatic walls.*
Solution Control	Under relaxation values – *Default*
Solution Method	Pressure Velocity Coupling Scheme – *Coupled* Spatial Discretization o Gradient - *Least Squares Cell-Based* o Pressure, Momentum, Turbulence Kinetic Energy, Turbulence Dissipation Rate, Energy - *Second-Order Upwind*

IV. RESULTS

Since there are several parametric models, the following data set was used to illustrate the final outcomes of the simulations.

D_{In}	Producer gas nozzle diameter	5 mm
D_{Air}	Air inlet diameter	6 mm
V_{INPG}	PG inlet velocity	14 ms^{-1}
D_{Out1}	PG inlet diameter	14mm
D_{Out2}	Mixture outlet diameter	14mm

Illustrations of velocity and PG mass fraction distribution using contours and volume renderings are shown in Fig. 8, Fig. 9, and Fig. 10.

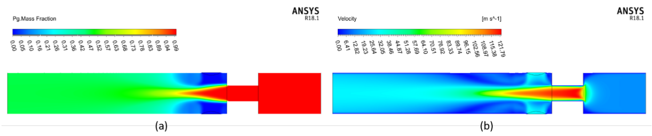


Fig. 8. Cross-sectional view of (a) PG mass fraction (b) Velocity distribution Contours

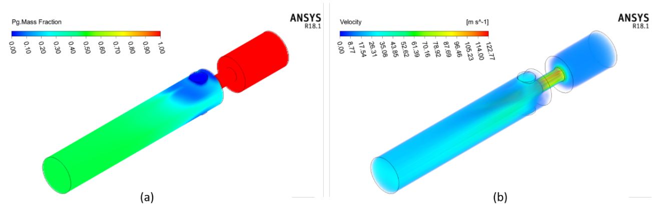


Fig. 9. Volume rendering of (a) PG mass fraction (b) Velocity distribution

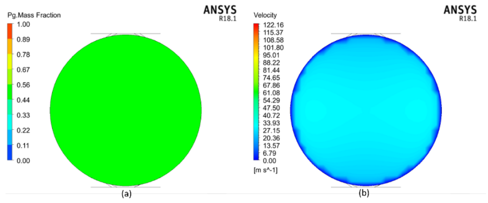


Fig. 10. Properties at the outlet (a) PG mass fraction (b) Velocity contours

The relationship between the outlet producer gas (PG) mass fraction and the diameters of the air and PG inlets is shown in Fig. 11. The results indicate that the PG mass fraction at the outlet increases with both the inlet diameter (D_{in}) and the air inlet diameter (D_{Air}). Additionally, Fig. 12 illustrates the relationship between the outlet PG mass fraction and the PG inlet velocity. The PG mass fraction at the outlet decreases with the reduction of PG inlet velocity up to a critical point. Beyond this critical velocity, air mixing completely stops, and the PG mass fraction reaches a value of 1, meaning the outlet consists solely of producer gas. Understanding these behaviors was crucial for finalizing the models for manufacturing.

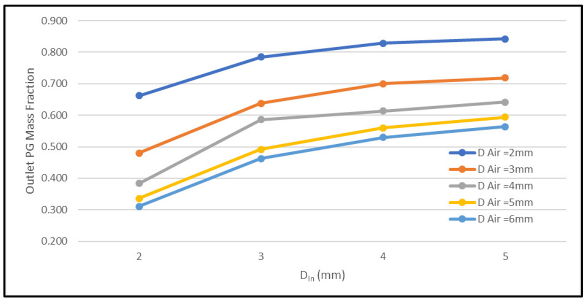


Fig. 11. PG mass fraction at outlet vs air inlet diameter

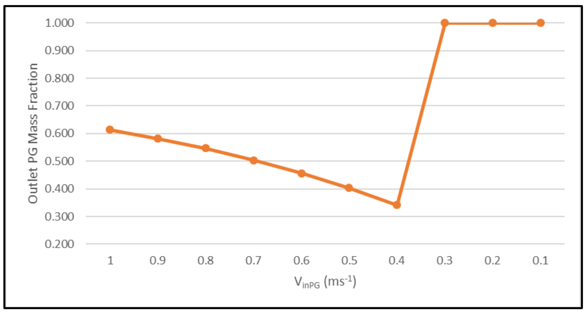


Fig. 12. PG mass fraction at outlet vs PG inlet velocity

The required producer gas (PG) mass fraction and outlet velocity for proper engine operation were determined. For an air-fuel ratio of 1.36, the PG mass fraction at the engine inlet is 0.4237. The air-fuel mixture inlet velocity was calculated based on an engine speed of 3000 rpm, an engine capacity of 150 cc, and a gas mixture outlet diameter of 14 mm. The required volume flow rate for the air-fuel mixture is 3.75×10^{-3} m^3s^{-1}. Given the model dimensions, the required velocity at the mixture outlet is 24.36 ms^{-1}.

If the outlet mixture velocity is higher than 24.36 ms^{-1}, it can be accepted but that velocity must satisfy the PG Mass fraction. That means for the velocities above 24.36 ms^{-1}, PG mass fraction should be 0.42. Until the above condition is satisfied rest of the simulations are conducted and it gives several combinations of parameters to obtain both producer gas mass fraction and required mixed flow velocity. (Refer to Appendix A).

V. Discussion

The design and simulation of a carburetor to run an internal combustion engine on producer gas present several unique challenges and opportunities. The low energy density of producer gas compared to conventional fuels like gasoline and natural gas necessitates a specialized carburetor design that can maintain an optimal air-fuel ratio, ensuring efficient combustion and engine performance.

The simulations carried out for different carburetor models revealed critical insights into the mixing behavior of air and producer gas. The initial models faced issues related to incomplete mixing and safety concerns, particularly the risk of backfire due to the accumulation of fuel-air mixtures in the chamber. These challenges underscore the importance of achieving a homogenous mixture while minimizing the volume of pre-mixed gases to reduce the risk of explosion.

Model 03, which employed a Bunsen burner mechanism, showed significant improvements over previous designs. By optimizing the number and positioning of air inlet holes, this model achieved a more uniform distribution of producer gas in the air-fuel mixture, leading to better combustion stability. The use of ANSYS simulations allowed for precise control over variables such as nozzle diameter, air inlet size, and gas velocity, providing a comprehensive understanding of how these factors influence the mixing process.

However, despite these advancements, the practical implementation of the designed carburetor would require further refinement. The results indicated that while the model could theoretically maintain the required air-fuel ratio, real-world variables such as engine load variations, ambient temperature changes, and fuel composition fluctuations might necessitate adaptive control mechanisms to ensure consistent performance.

The study also highlights the broader implications of using producer gas as a fuel. Given its renewable nature and the increasing scarcity of fossil fuels, optimizing internal combustion engines to run on biomass-derived gases could significantly contribute to sustainable energy solutions. However, the lower calorific value of producer gas remains a limitation, leading to reduced engine power output compared to conventional fuels. This trade-off must be carefully considered in applications where power density is critical.

VI. CONCLUSION

This study successfully designed and simulated a carburetor capable of running an internal combustion engine on producer gas. Through iterative modeling and simulation using ANSYS, the final design demonstrated improved mixing of air and producer gas, achieving the necessary stoichiometric air-fuel ratio for stable engine operation. Model 03, in particular, emerged as the most effective design, offering a practical solution to the challenges posed by the low energy density of producer gas.

The research contributes to the ongoing development of alternative fuel technologies, particularly in the context of utilizing renewable biomass resources. While the designed carburetor shows promise for real-world applications, further testing and refinement are necessary to address the practical challenges identified during the simulation process. Future work should focus on integrating adaptive control systems to accommodate variable operating conditions and exploring methods to enhance the energy density of producer gas. Overall, this work demonstrates the feasibility of using producer gas in internal combustion engines, offering a pathway towards more sustainable and eco-friendly energy solutions in the face of depleting fossil fuel reserves.

ACKNOWLEDGMENT

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APPENDIX A

Simulations for Barrel Size 13mm

REQUIREMENT

- Outlet PG Mass fraction = 0.4237
- Outlet Mixture Velocity = 28.25 ms^{-1}

Model No	PG inlet Velocity	D_{in}	D_{air}	Outlet PG Mass Fraction	Outlet average velocity
Units	$m\,s^{-1}$	mm	mm		$m\,s^{-1}$
1	12	5	3	0.675088	16.7958
2	12	5	4	0.53345	20.6986
3	12	5	8	0.356626	29.8529
4	13	5	3	0.682646	18.0218
5	13	5	4	0.553679	21.6839
6	13	5	5	0.468429	25.2423
7	13	5	6	0.418703	27.9775
8	14	5	4	0.571057	22.7165
9	14	5	5	0.485376	26.3079
10	14	5	6	0.435369	29.0732
11	14	5	8	0.389696	32.0303
12	12	6	3	0.707327	16.1249
13	12	6	5	0.455725	23.902
14	12	6	6	0.408862	26.4324
15	12	6	7	0.386445	27.8425
16	12	6	8	0.372239	28.7253
17	13	6	3	0.712466	17.3556
18	13	6	4	0.563476	21.3421
19	13	6	5	0.476523	24.8579
20	13	6	6	0.431796	27.2163
21	13	6	7	0.408673	28.5908
22	13	6	8	0.395063	29.411
23	14	6	3	0.717659	18.5644
24	14	6	4	0.579405	22.4249
25	14	6	5	0.496562	25.7691
26	14	6	6	0.454102	27.9515
27	14	6	7	0.429233	29.3797
28	14	6	8	0.416683	30.134
29	12	7	3	0.72282	15.8255
30	12	7	4	0.563205	19.7318
31	12	7	5	0.466357	23.4191
32	12	7	6	0.419468	25.8267
33	12	7	7	0.39556	27.3394
34	12	7	8	0.37915	28.2993
35	13	7	3	0.732577	16.9432
36	13	7	4	0.580908	20.7886
37	13	7	5	0.488332	24.3399
38	13	7	6	0.443838	26.5579
39	13	7	7	0.420114	27.9834
40	13	7	8	0.404245	28.8287
41	14	7	3	0.741443	18.0552
42	14	7	4	0.597278	21.8432
43	14	7	5	0.509865	25.2156
44	14	7	6	0.466932	27.2841
45	14	7	7	0.443095	28.6464
46	12	7	8	0.37915	28.2993
47	12	8	3	0.732046	15.6426
48	12	8	4	0.571932	19.4582
49	12	8	5	0.472566	23.1061
50	12	8	6	0.424037	25.5413
51	12	8	7	0.39806	27.0993
52	13	8	3	0.745465	16.6845
53	13	8	4	0.591095	20.4631
54	13	8	5	0.49648	23.9585
55	13	8	6	0.449726	26.2374
56	13	8	7	0.425063	27.6304
57	13	8	8	0.411281	28.4782
58	14	8	3	0.756629	17.7382
59	14	8	5	0.51965	24.7838
60	14	8	6	0.474631	26.891
61	14	8	7	0.45088	28.1945
62	14	8	8	0.436275	28.9817

Note: Green – Rich Mixture (>0.5)
Red – Acceptable Margin of PG Mass fraction(0.43<X<0.5)
Black – Lean Mixture (<0.43)
Yellow – Acceptable Outlet Velocity (>28.25)
Suggested Models for manufacturing: **10, 45, 62**

Simulations for Barrel Size 14mm

REQUIREMENT

- Outlet PG Mass fraction = 0.4237
- Outlet Mixture Velocity = 24.36 ms^{-1}

Model No	PG inlet Velocity	D_{in}	D_{air}	Outlet PG Mass Fraction	Outlet average velocity
Units	$m\ s^{-1}$	mm	mm		$m\ s^{-1}$
1	14	5	3	0.737026	18.1666
2	14	5	4	0.618312	21.2023
3	14	5	8	0.455132	28.033
4	15	5	3	0.736869	19.4707
5	15	5	4	0.61748	22.7209
6	15	5	5	0.528999	26.1023
7	15	5	6	0.482568	28.4212
8	16	5	4	0.617049	24.2643
9	16	5	5	0.528445	27.9365
10	16	5	6	0.48207	30.3872
11	16	5	8	0.453376	32.1356
12	14	6	3	0.77184	17.453
13	14	6	5	0.597566	21.8831
14	14	6	6	0.557387	23.2892
15	14	6	7	0.530696	24.3941
16	14	6	8	0.52354	24.6901
17	15	6	3	0.771335	18.6957
18	15	6	4	0.669756	21.1341
19	15	6	5	0.522693	26.4829
20	15	6	6	0.55626	25.0451
21	15	6	7	0.528964	26.1883
22	15	6	8	0.521837	26.5641
23	16	6	3	0.771281	19.9526
24	16	6	4	0.6696	22.5798
25	16	6	5	0.596344	25.0671
26	16	6	6	0.555267	26.7219
27	16	6	7	0.528209	28.0027
28	16	6	8	0.521406	28.3238
29	14	7	3	0.820316	16.5997
30	14	7	4	0.734812	18.2537
31	14	7	5	0.673745	19.7023
32	14	7	6	0.639336	20.6223
33	14	7	7	0.621992	21.1453
34	14	7	8	0.606613	21.6951
35	15	7	3	0.820203	17.7882
36	15	7	4	0.734332	19.5621
37	15	7	5	0.673124	21.138
38	15	7	6	0.639066	22.1083
39	15	7	7	0.620858	22.6852
40	15	7	8	0.605322	23.3096
41	16	7	3	0.819234	18.9936
42	16	7	4	0.733455	20.8925
43	16	7	5	0.673007	22.5434
44	16	7	6	0.638256	23.6126
45	16	7	7	0.619995	24.2442
46	16	7	8	0.603866	24.8964
47	14	8	3	0.940768	14.7811
48	14	8	4	0.876192	15.715
49	14	8	5	0.786699	17.2512
50	14	8	6	0.729221	18.435
51	14	8	7	0.6888	19.3284
52	15	8	3	0.939987	15.8454
53	15	8	4	0.87609	16.8423
54	15	8	5	0.785511	18.4988
55	15	8	6	0.728116	19.7604
56	15	8	7	0.6868	20.7593
57	15	8	8	0.734299	19.3741
58	16	8	3	0.939464	16.9102
59	16	8	5	0.784664	19.7528
60	16	8	6	0.726751	21.1264
61	16	8	7	0.685131	22.1946
62	16	8	8	0.733144	20.7195

Note: Green – Rich Mixture (>0.5)
Red – Acceptable Margin of PG Mass fraction(0.43<X<0.5)
Black – Lean Mixture (<0.43)
Yellow – Acceptable Outlet Velocity (>24.36)
Suggested Models for manufacturing: **3, 7, 10, 11**

Simulations for Barrel Size 15mm

REQUIREMENT

- Outlet PG Mass fraction = 0.4237
- Outlet Mixture Velocity = 21.22 ms^{-1}

Model No	PG inlet Velocity	D_{in}	D_{air}	Outlet PG Mass Fraction	Outlet average velocity
Units	$m\ s^{-1}$	mm	mm		$m\ s^{-1}$
1	15	6	8	0.492621	28.0021
2	15	5	8	0.396135	33.8783
3	15	4	8	0.337083	39.4551
4	11	4	8	0.306821	31.4639
5	11	5	8	0.337923	28.7563
6	11	6	8	0.34886	27.9328
7	10	4	7	0.319693	27.5613
8	10	5	7	0.33888	26.1218
9	10	6	7	0.348368	25.5142
10	9	7	8	0.302265	26.2364
11	9	8	8	0.303124	26.1512
12	9	9	8	0.30125	26.2986
13	10	6	8	0.324166	27.2166
14	10	5	6	0.383584	23.3338
15	10	5	5	0.457147	19.8622
16	10	5	4	0.551604	16.765
17	10	5	3	0.684163	13.8503
18	11	5	5	0.475659	21.0675
19	11	6	6	0.413979	23.9268
20	11	6	7	0.37312	26.3184
21	11	6	8	0.34886	27.9328
22	11	6	9	0.33684	28.7908
23	11	4	4	0.546493	18.5997
24	11	4	5	0.449909	22.166
25	11	4	6	0.379062	25.9255
26	11	4	7	0.33286	29.2132
27	12	5	4	0.586445	19.0429
28	12	5	5	0.49273	22.2581
29	11	6	5	0.48805	20.5897
30	10	7	6	0.398832	22.5181
31	11	9	8	0.357933	27.3929
32	12	9	7	0.408287	26.4279
33	13	9	9	0.400442	29.0415

Note: Green – Rich Mixture (>0.5)
Red – Acceptable Margin of PG Mass fraction(0.43<X<0.5)
Black – Lean Mixture (<0.43)
Yellow – Acceptable Outlet Velocity (>21.22)
Suggested Models for manufacturing: **1, 24, 28**