# Performance and Emission Improvement through Optimization of Venturi Type Gas Mixer for CNG Engines

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**Abstract -** ***Carburetor design plays important role either in the conventional CNG fuelled or dual fuel engines. The main challenge focuses on designing a gas mixing device which mixes the supplied gas in the incoming air at an optimum ratio. In order to optimize the mixture quality near about stoichiometric ratio even at full load conditions, empirical relationships between input and output variables should be established in order to predict the desired output. This paper mainly focuses on the optimization of different parameters such as throat diameter, hole diameter, number of holes, convergent and divergent angle. Their experimental results are analyse to select optimum configuration. Fulfilling need of the design, five venturi configurations are designed and manufactured by making variation in throat diameter and number of holes. Venturi number 3 is found to be optimum designed venturi because during actual test conditions at full load performance lambda observed very close to 1 and equivalence ratio observed close to 0.88, desired for smooth operation of CNG engines at its all operating points. Also brake specific fuel consumption and exhaust emission found to be minimum compared to other venturies. Which satisfies the design requirement for CNG engines operating in open loop system.***

***Key Words:*** *CNG, Stoichiometric ratio, Venturi type gas mixer*

## 1. INTRODUCTION

The energy requirements of ever growing population and subsequent growing sector of transports, mostly depend on reserves of crude oil which are depleting at rapid rates and expected to be vanishes in future which is not very distant. Foreign exchange expenditure for import of crude oil, fluctuations of their prices and increasingly stringent exhaust emission legislation have led to rise in necessity of using alternative fuels in internal combustion engines. Due to these major reasons, all the automobile manufacturers turn their research direction towards feasible alternative fuel for IC engines. Numerous researches are being carried out worldwide in alternative fuels or sources of energy such as biodiesel, alcohols, bio-ethanol, hydrogen, liquefied petroleum gas (LPG) and compressed natural gas (CNG). As a result vehicles are available in the market which can be run on alternative fuel with conventional fuel as in bi-fuel or dual fuel mode. Among all of these, CNG is majorly used as alternative fuel because of its feasibility which is inline technology of current engines. Compressed natural gas (CNG) is attractive for main reasons such as cheaper fuel than gasoline or diesel. It has inherently less air pollution and greenhouse gas emission. In current trend of gas mixer technology natural gas can be mixed homogeneously with air at different mixture strengths and engine can run under both stoichiometric as well as lean mixture condition. Main features of this technology are its cost effective operation, modular nature and easy adaptation on current generation of vehicles. The CNG has very low carbon contain which eliminates the emission of particulate matter like other conventional fuel. These gaseous fuels are having very simple carbon chain structure with lower carbon to hydrogen ratio of fuel compared to all other crude oil products. Following table shows the properties comparison of alternative fuel with conventional fuel [1, 2].

**Table 1: Properties of Gasoline, Diesel and CNG [3, 4, 5, 6]**

| Sr. No. | Property | Unleaded gasoline | Diesel | CNG |
|---|---|---|---|---|
| 1 | Research octane number | 92-98 | 30 | 120 |
| 2 | Density at 16℃ and 1.01 bar ($kg/m^3$) | 721-785 | 833-881 | 0.72 |
| 3 | Net heating values ($MJ/kg$) | 43.9 | 42.5 | 45.8 |
| 4 | Flame velocity ($cm/s$) | 37-43 | 30 | 38 |
| 5 | Flammability limits (volume % in air) | 1.4-7.6 | 0.7-5 | 0.4-1.6 |
| 6 | Auto ignition temperature ($K$) | 533-733 | 530 | 723 |
| 7 | Stoichiometric ratio on mass basis | 14.6 | 14.5 | 14.49 |

## 2. DESIGN OF VENTURI TYPE GAS MIXER

Gas mixer is a device used to determine the amount of natural gas and air before entering the engine. It injects the gas into the intake air stream of an internal combustion chamber using a combination of radial holes and radial tubes located around the perimeter of an air flow passage [7]. The designing of gas mixture venturi is important to keep the mixture in laminar flow in venturi for proper mixing of gas into incoming air [8].

Too small throat causes air flow restriction at the throat whereas too big throat causes small pressure drop at the throat to initiate gas entry. This is undesirable for better mixing fuel and air. Similarly more hole diameter and number of holes gives rich mixture whereas less hole diameter and number of holes provide lean mixture [9]. Increased throat diameter has given good test results because of less pressure drop created at throat [10]. Required air flow rate for the engine operation has to be determine. It can be found by solving the equation below:

$$Q_a = \frac{N \eta_v V_d}{2 \times 60} \quad .... (1)$$

Also the other dimension can be find out by applying Bernoulli's equation across venturi.

$$P1 + \frac{1}{2}\rho_1 \times V_1^2 = P2 + \frac{1}{2}\rho_2 \times V_2^2 \quad .... (2)$$

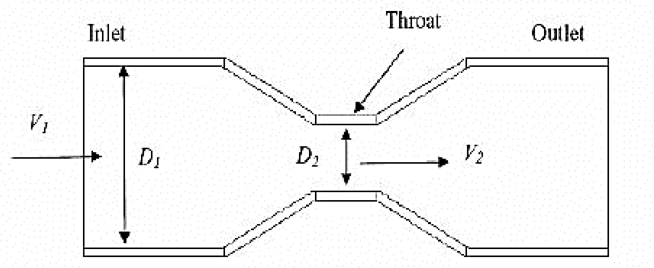


**Figure 1: Conceptual Gas Mixture [9]**

A venturi based on Bernoulli's equation consist of a tube with a contracted throat. This portion produces an increment in velocity by pressure reduction which followed by gradually diverging portion. In diverging portion velocity is transformed into pressure with slight friction loss. The principle characteristic of a CNG mixer is that, the change in velocity causes difference in pressure within the contraction passage. This change in pressure causes flow of the fuel to mix with the main airflow in the required proportion [11].

Optimum venturi design is important because the combustion efficiency is directly proportional to the degree of homogeneous mixing. It is also important for proper mixing of air, prior to entry in the combustion chamber [12]. When the flow of air through the carburetor increase, its fuel flow remains constant. So, the mixture becomes leaner. When the pressure at the throat decreases with increase in opening of the throttle plate, the flow of fuel from the float chamber into the throat increases. Hence in both condition the quality of the mixture tends to remain constant [13]. The venturi type gas mixer seems to be efficient for better mixing of CNG and air than existing T-junction type gas mixers which developed earlier for mixing of air and gases in dual fuel engines [14].

Table 2 shows the calculated parameter for the design of gas mixture venturi based on the engine operating requirements. In order to optimise the venturi parameters the performance is carried on 5 venturies which are designed for optimum performance for given engine.

**Table 2: Design Parameters of Venturi**

| Sr.No. | Calculated Parameter | Values |
|---|---|---|
| 1 | Maximum air flow ($m^3/sec$) | $7.92\times10^{-3}$ |
| 2 | Minimum air flow ($m^3/sec$) | $5.28\times10^{-3}$ |
| 3 | Maximum inlet velocity of air ($m/s$) | 6.34 |
| 4 | Minimum inlet velocity of air ($m/s$) | 4.22 |
| 5 | Velocity of air at throat ($m/s$) | 31.33 |
| 6 | Diameter at throat ($mm$) | 19 |
| 7 | Maximum CNG flow rate ($kg/hr$) | 3.87 |
| 8 | Minimum CNG flow rate ($kg/hr$) | 2.58 |
| 9 | Maximum velocity CNG flow rate($m/s$) | 5.85 |
| 10 | Minimum velocity CNG flow rate($m/s$) | 3.308 |
| 11 | Throat length($mm$) | 5 |
| 12 | Length of convergent portion($mm$) | 23 |
| 13 | Length of divergent portion($mm$) | 15 |

Various configuration of the venturies used for the testing are as follows. Venturies are designated as venturi number and its parametric configuration. (Venturi number - Throat diameter × Hole diameter × Number of holes)

- Venturi Number 1 (V1) - ϕ25×3×12
- Venturi Number 2 (V2) - ϕ23×3×12
- Venturi Number 3 (V3) - ϕ23×3×08
- Venturi Number 4 (V4) - ϕ23×3×10
- Venturi Number 5 (V5) - ϕ24×3×12

## 3. EXPERIMENTAL PROCEDURE

Figure 2 shows the experimental setup used for the testing of the CNG fuelled engine. It consist the multi fuel VCR engine coupled to eddy current dynamometer.

The CNG kit outlet is attached to engine intake manifold. Single stage pressure regulator is used to reduce CNG gas cylinder pressure from 200 bar to 2 to 1.5 bar. The CNG cylinder is kept on weighing machine to record gas consumption per hour. The engine control system is connected to the computer for acquitting data from engine data acquisition system and it generates the results on the computer.

The CO, HC, $CO_2$, $O_2$ and $NO_x$ were measured using AVL DiGas 444 5-Channel emission gas analyzer.


**Figure 2: Experimental Setup**

Base performance of the engine is conducted with existing gasoline engine setup. The base readings are taken to confirm the engine performance. Here, the compression ratio 10 is considered as optimum for the gasoline engines fuelled with CNG as a multi fuel engine or bi-fuel engine. As per requirement for CNG fueling, engine preparation is made and then experimentation started.

CNG kit along with the gas mixture venturi is attached to engine intake manifold. The readings are taken for different speed conditions ranging from 1800 *rpm* to 1000 *rpm* with wide open throttle condition. The same approach is adopted for all other venturies. Performance data is recorded in computer by enginesoft software package and emissions are recorded from emission gas analyser.

**Table 3: Engine Specification**

| Engine Specification | |
|---|---|
| Model | TV1 |
| Make | Kirloskar |
| Power (*kW*) | 3.5 |
| Rated speed (*rpm*) | 1800 |
| Cylinder bore (*mm*) | 87.5 |
| Stroke (*mm*) | 110 |
| Connecting rod (*mm*) | 234 |
| Compression ratio (VCR) | 6-10 |
| Stroke type | 4 stroke |
| Number of cylinder | 1 |
| Cooling Type | Water |
| Fuel | Gasoline |
| Swept volume (*cc*) | 661.5 |

The performance and emission parameters which are under consideration and measurement are as follows:

- Power and Torque
- Brake Thermal Efficiency
- Specific Fuel Consumption
- Lambda Values
- Exhaust Emissions

## 4. RESULTS AND DISCUSSION

The results obtained from the experimentation are put into the comparison for all venturi. Comparison are based on full throttle performance parameters with all the venturies to find out optimum venturi configuration. The engine is kept in full warm up condition and then performance is carried out from rated speed to low end torque speed point of the engine. The major parameters such as torque, power, BSFC, lambda values and exhaust emissions were recorded.

### 4.1 Performance Parameters

#### 4.1.1 Torque

Figure 3 shows that, the venturi number 1 produces more torque as compared to other venturies between speed ranges of 1800 -1500 *rpm* due to better combustion and metered air fuel mixture to the engine. Hence, maximum combustion pressure is observed. The peak torque produced by the venturi number 3 is 18.8 *N.m* @ 1000 *rpm* because of rich mixture. Still torque produced by other venturies are closely in line with each other.

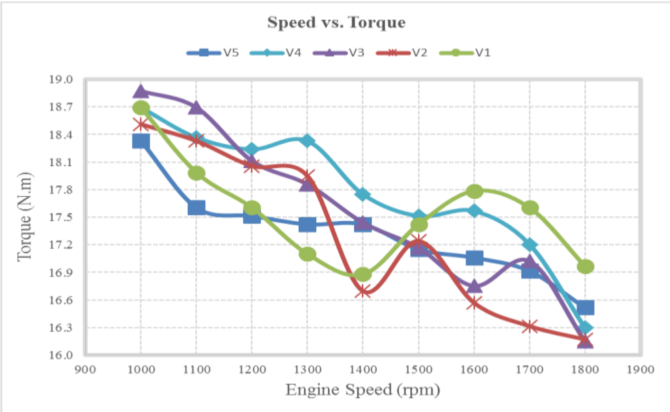


**Figure 3: Variation of Torque with Engine Speed**

#### 4.1.2 Power

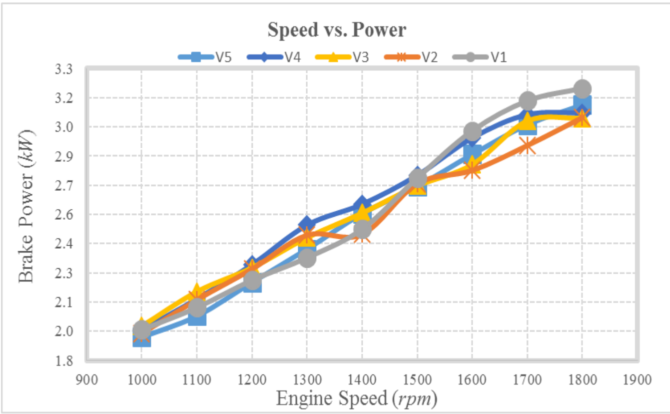


**Figure 4: Variation of Brake Power with Engine Speed**

Figure 4 shows that, the venturi number 1 produces more brake power as compared to other venturies between speed ranges of 1800 -1600 *rpm.* Whereas brake power produced by other venturies are closely in line with each other. The brake power produced by the venturi number 1 is 3.2 *kW* @ 1800 *rpm*. The power produced is more due to better volumetric efficiency and metered air fuel mixture to the engine due to which complete combustion observed.

### 4.1.3 Brake Specific Fuel Consumption

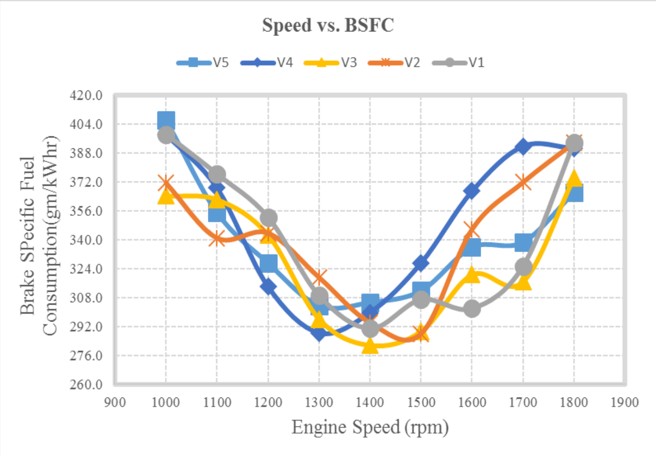


**Figure 5: Variation of BSFC with Engine Speed**

Figure 5 shows that, the venturi number 3 gives lower brake specific fuel consumption as compared to other venturies between speed ranges of 1500 -1300 *rpm* The reduction in BSFC is due to better air fuel mixture preparation and metered air fuel mixture to the engine operating close to lambda 1. The lowest BSFC observed with the venturi number 3 is 281.6 *gm/kWhr* @ 1400 *rpm*.

### 4.1.4 Lambda

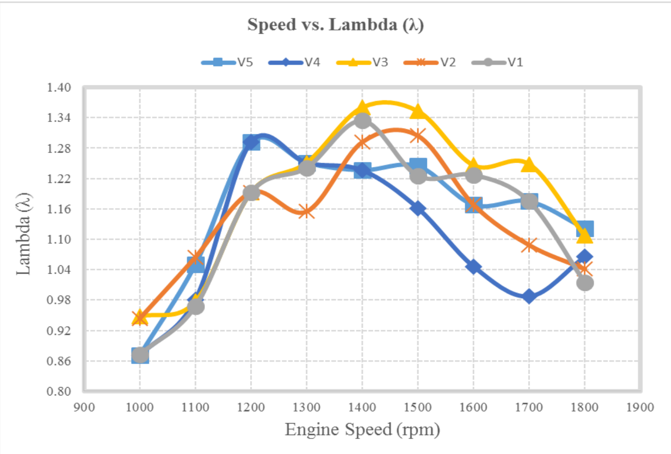


**Figure 6: Variation of Lambda with Engine Speed**

Figure 6 shows that, the venturi number 3 gives lean mixture compared to other venturies between all speed ranges of performance. Lambda values of other venturies are spread widely over the performance range. Also the average lambda achieved from venturi number 3 is always on leaner side compared to other venturies. Even with open loop system the venturi number 3 maintain the lambda in range of 1.2 to 0.9 (± 10 to 15%) only which is close to lambda one. This helps to achieve the lowest BSFC with better torque and power.

### 4.1.5 Equivalence Ratio

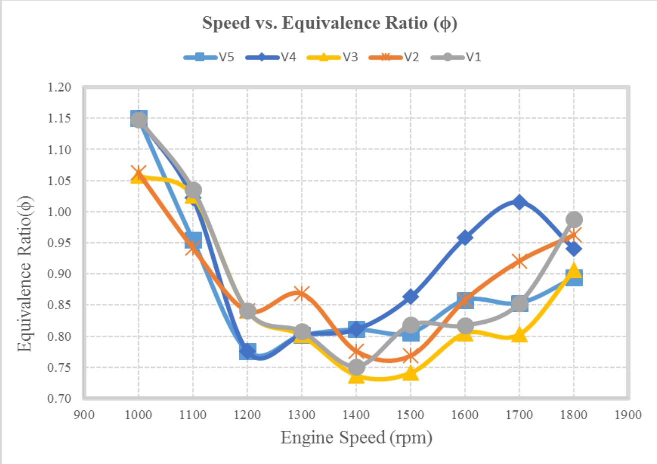


**Figure 7: Variation of Equivalence Ratio with Engine Speed**

Figure 7 shows that, the venturi number 3 gives better equivalence ratio as compared to other venturies in speed ranges above 1300 *rpm*. Even with open loop system the venturi number 3 maintain the equivalence ratio from 0.74 to 0.98 (± 10 to 15%) which is close to equivalence ratio of 0.88 desired for CNG engines.

## 4.2 Emission Parameters

### 4.2.1 Carbon Monoxide (CO)

Figure 8 shows that, the venturi number 3 gives lower CO emission as compared to other venturies between speed ranges of 1500 to 1000 *rpm*. Whereas CO emission of other venturies are higher in the performance range because of rich mixture and low temperature of combustion especially at low speed. The raw emission values of CO can be reduce further by strictly maintaining lambda one.

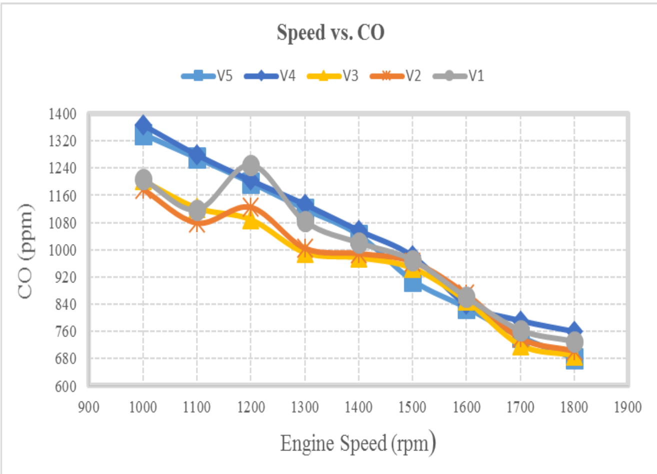


**Figure 8: Variation of CO Emission with Engine Speed**

### 4.2.2 Hydrocarbon (HC)

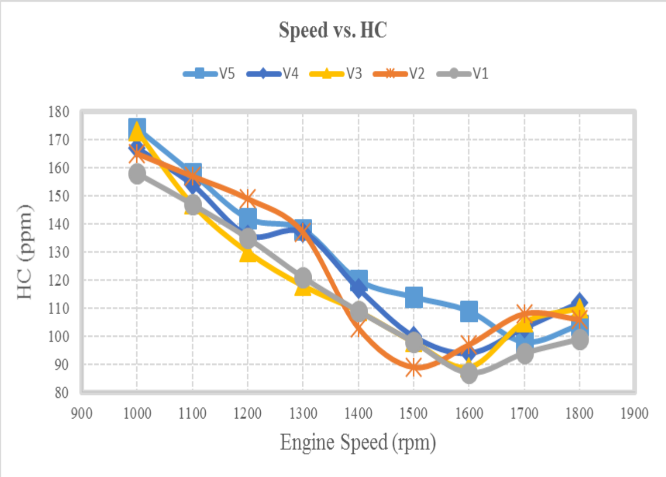


**Figure 9: Variation of HC Emission with Engine Speed**

Figure 9 shows that, the venturi number 1 gives lower HC emission values as compared to other venturies above 1550 *rpm* speed range. The raw emission of HC with venturi number 1 and 3 is lower compared to other venturies because of lean mixture and subsequent better combustion of mixture.

### 4.2.3 Oxides of Nitrogen ($NO_x$)

Figure 10 shows that, the venturi number 3 gives lower $NO_x$ emission values as compared to other venturies between speed ranges of entire performance. Whereas $NO_x$ emission of all venturies are lower in the speed range of 1300 to 1500 *rpm* because of correct mixture formation and sufficient timings for combustion.

The $NO_x$ emission with optimized venturi number 3 is lower compared to other venturies because of leaner mixture formation.

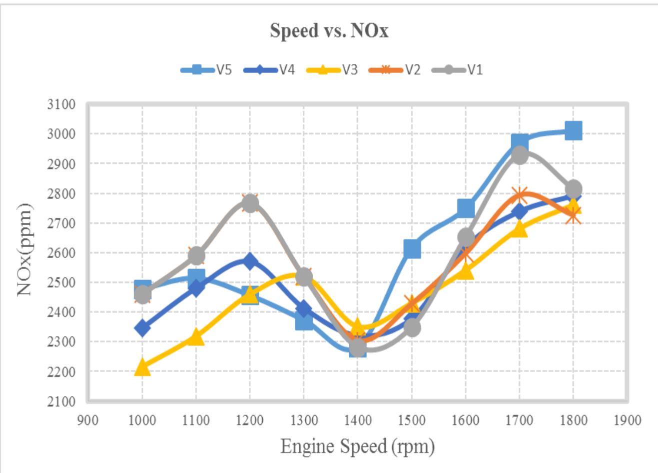


**Figure 10: Variation of $NO_x$ Emission with Engine Speed**

## 5. CONCLUSIONS

Fulfilling the need from design and the experimental results discussed in the above section following conclusions can be drawn.

- By optimising the venturi type gas mixer parameters, improvement in engine performance and exhaust emissions is observed.
- It is seen that gas mixture venturi number 3 with 8 holes helps to maintain lean mixture throughout the performance of engine compared to all other type of gas mixture venturies.
- The simultaneous increase in throat diameter help to improve volumetric efficiency of the engine since small throat diameters restricts the air flow.
- Brake power and torque drops slightly at rated speed with gas mixer venturi number 3 due to lean mixture. This indicates that reduction in the number of holes is hardly possible.

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## NOMENCLATURE

| | |
|---|---|
| $D_1$ | Inlet diameter of venturi (*m*) |
| $D_2$ | Diameter of throat (*m*) |
| $Q_a$ | Required airflow rate (*m³/s*) |
| $\eta_v$ | Volumetric efficiency (%) |
| $V_d$ | Volume displacement (*m*) |
| N | Engine speed (*rpm*) |
| $P_a$ | Ambient air pressure (*Pa*) |
| $P_t$ | Pressure at throat region (*Pa*) |
| $\rho_a$ | Density of ambient air ($kg/m^3$) |
| $\rho_t$ | Density at throat region ($kg/m^3$) |
| $V_a$ | Velocity of ambient air (*m/s*) |
| $V_t$ | Velocity of air at throat (*m/s*) |