EXPERIMENTAL ANALYSIS OF FEEDBACK CONTROL SYSTEM FOR LAMBDA SENSOR BASED PRODUCER GAS ENGINE CARBURETOR

Authors: *Sumer B. Dirbude*[*], *Sheshagiri G.S*[**], *Dr.N.K.S.Rajan*[***]

ABSTRACT:
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. The study reported in this paper forms an initial experimentation efforts for the development of the lambda sensor based Producer gas carburetor for frequent load changes and throw off conditions using feedback control system. This paper aims on the experimentations carried out for the design confirmation of the control and actuation parts and discuss the results obtained.

Keywords*: producer gas, lambda sensor, Y-type carburetor, control valve.*

INTRODUCTION

Producer gas obtained through thermo chemical conversion of Biomass, can be used for power generation via internal combustion engine route. Commercially no special producer gas engine is available. As such there are no carburetors are available for such low energy density gaseous fuel. The carburetors available for other gaseous fuels namely the natural gas, Biogas and landfill gas is unsuitable due to widely different stoichiometric air to fuel requirement. The stoichiometric air to fuel requirement ratio varies between 10 to 6 (on volume basis) for fuel such as natural gas and biogas/landfill gas based on methane content in the gas. However, stoichiometric air to fuel ratio for producer gas is about 1.2 to 1.4 (on volume basis) based on constituents of gas. So it is necessary to have the carburetor which will maintain required air to fuel ratio with load variation, smooth operation with minimal pressure loss etc.

Attempts have been made by Combustion, Propulsion and Gasification Laboratory at Indian Institute of Science, Bangalore on the development of the producer gas (PG) carburetor to fulfill the unavailability of PG carburetor and the non adaptability of biogas carburetor. [1]

The Version I is based on IMPCO carburetor, meant for biogas/land fill gas. During the trial runs with Version I(on Greaves engine),the carburetor performed satisfactorily up to load of 70 kWe, beyond which there was starvation air based on oxygen measurements in the exhaust. With the additional provisions to bleed air, the engine could take up higher load. Moreover, in this version, the gas flowed over the plunger and resulted in deposition of water/ contaminants in the gas if any.

The Version II included the improvements over the Version I other than providing flexibility of making modifications in the hardware with minimal downtime.

Version III is the Y- type carburetor designed to operate in conjunction with zero pressure regulator which fulfill the

[*] M.E. project student; [**] Electronics engineer, CGPL, IISc; [***] Principal Research Scientist, CGPL, IISc, Bangalore

air to fuel ratio requirements, smooth operation with minimal pressure loss etc.However, the engine with carburetor with zero pressure regulator, shows some problem. The problem is mainly noticed during sudden load change and load throw off conditions because of hysterisis and sluggish response of the carburattor.When the engine is running at high load, the mixture flow rates will be very high in order to meet the power demand. Under this condition of high flow rate, if there is sudden and drastic fall of load on the engine or the load is completely thrown off, the speed of the engine starts to increase and to prevent this the governor comes into play and reduce the throttle valve opening possibly with some overcorrection especially during load through offs. This sudden closure of the throttle valve leads to pressure build up upstream of the throttle valve. The air side being almost freely connected to the atmosphere except for the air filter is able to transmit the pressure pulse out. However, on gas side, the same pressure pulse cannot be transmitted back all the way back because of sluggish response of the zero pressure regulators. Due to this for a small duration the pressure difference between the gas line near the zero pressure regulators and the throttle is much greater as compared to the pressure difference on the air side between air line and the throttle. Since mass flow rate is proportional to the square root of the pressure difference driving it, it can be seen that on the gas side there is greater flow as compared to air side. When Engine is used for grid application the hysterisis and sluggishness of the zero pressure regulators generally leads to the richening of the mixture which cause backfiring problems.

In order to overcome the problem associated with the use of the zero pressure regulators, the lambda sensor based PG carburetor has been designed.

EXPERIMENTAL SETUP

Figure (1) shows the experimental set-up that was built for testing the performance of the carburetor and the closed loop control system. An 80 Kg/hr open-top downdraft gasifier was used as the gas generator that was fed with either bamboo or casurina depending on the availability at the time of experiment. The gasifier has a suction blower, which ensures the delivery of the gas at a pressure slightly higher than atmospheric. This depends mainly on the valve position. The gas line has been split into three sections using ‘T’ joints with one line connected to the burner where initial flaring is done and the gas is allowed to burn till the gasifier stabilizes, the second line delivers gas to the engine and third line has been specifically drawn for the purpose of experimentation. The first and third lines

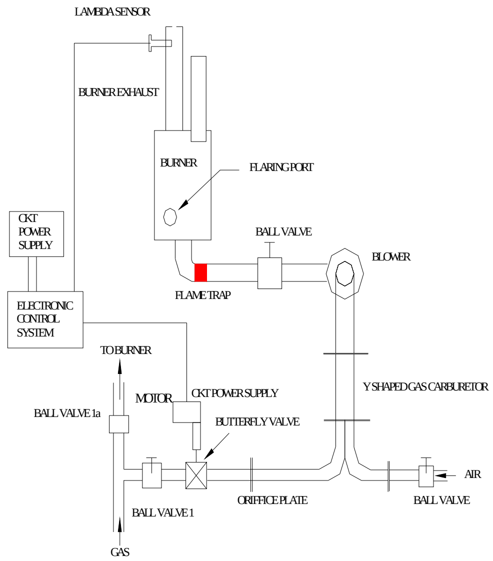


Figure (1) The experimental set-up

supplying gas to the burner and the experimental set up are shown in the figure. The two valves numbered ‘1’ and ‘1a’ are used to control the gas flow rates.

Coming to the experimental set-up, in the gas supply line the valve, which is basically a ball valve, is, used for general gas flow rate controls. The ball valve is necessary to set the different flow rates necessary for carrying out the experiment. After the ball valve, a butterfly valve (part of carburetor) is included in the gas line,

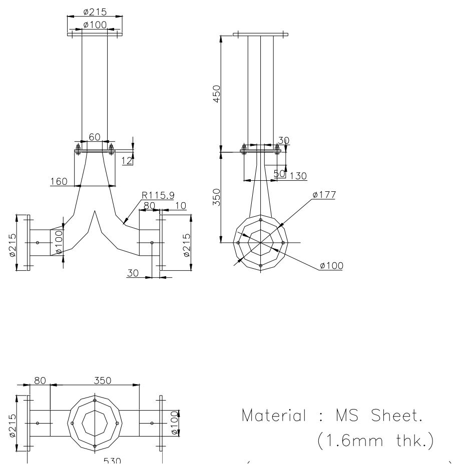


Figure (2): Producer gas carburetor

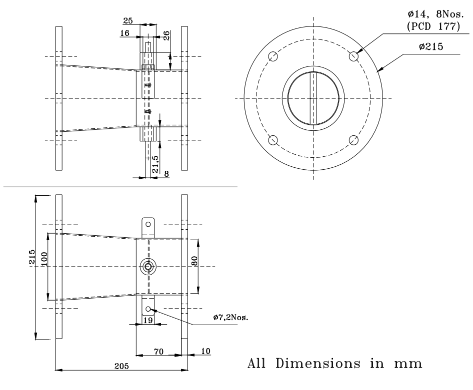


Figure (3): Butterfly type control valve

which acts to establish fine control in the gas flow rate. It is this valve, which is actuated by the geared motor to control the air fuel ratio. The gas line is then connected to one arm of the carburetor and at the point of connection; an orifice plate is included to measure the gas flow rate. Another arm of the carburetor is connected to the air line, which also has a ball valve and orifice plate. Measurement of air and gas flow rates gives an indication of the air-fuel ratio (while conducting experiments this part was avoided to have flexibility) which it would have experienced if it had been connected to an engine. Another ball valve is placed post blower to control the mixture flow rate. The mixture line is further connected to a stainless steel jet type burner. A flame trap is used as a precautionary measure to avoid any flashback since a stoichiometric mixture is being supplied. The burner is housed in a leak proof cylindrical shell, where the mixture of gas & air burns and escapes through three exhaust pipes to the atmosphere. The cylindrical shell has a flaring port through which a burning wick can be introduced to flare the burner. The flaring port can be closed once the ignition takes place.

One of the exhaust pipe has a small hole in which the Lambda sensor can be screwed. Another hole is also provided to draw small quantity of exhaust gas for analysis. The Lambda sensor is in turn connected to the electronic control system. The electronic control system triggers the geared motor based on the instantaneous lambda value. The geared motor is connected to the control valve that controls the gas flow rate to the carburetor.

A data acquisition system was used in order to collect the instant data values. The output from the Lambda sensor, the valve position and the circuit pulsing are the main values that were continuously acquired using the data acquisition system.

Between the burner and blower, flame trap was used to avoid the danger of flashback. In flame trap because of restriction to flow, the flow velocity is high and therefore, there is no possibility of flame travel beyond this point.

1. <u>Burner</u>: A jet type stainless steel burner as shown in figure (4) was used for experimentation. The burner has three jets of equal opening area. The burner is enclosed in a leak proof cylindrical shell of diameter 300 mm and height 700 mm. During the burning of mixture inside the shell, outside air cannot entrap into the shell. The shell material used is 1.6 mm MS sheet. On the top of the shell, three pipes of ϕ 80

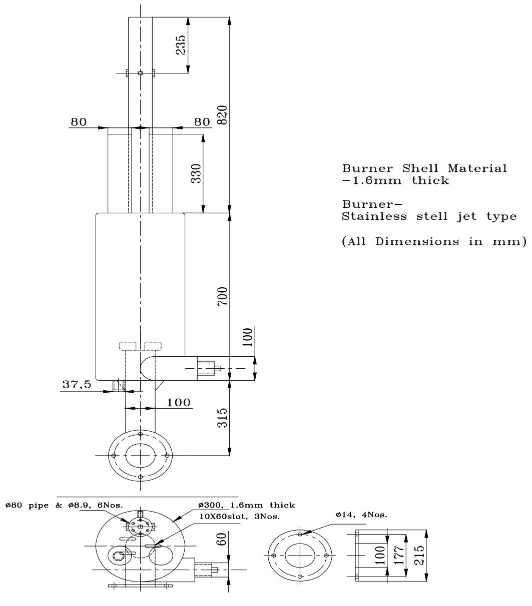


Figure (4): Gas / air burner

mm are welded to escape the flue gases. Out of these, in one pipe, arrangement for lambda sensor insertion and flue gas analyzer has been made and its top is closed with a cap having several holes in it. This was made to allow the exhaust gases to get mixed properly at the lambda insertion point. Whereas exhaust gases flow into the atmosphere without any interaction with sensor through other two pipes and avoids any pressure build up inside the burner shell. Arrangement for flaring of gas and air mixture is made at two locations; one just below the burner and other on the side of shell. These flaring ports can be closed after igniting the mixture. The burner shell was kept vertical during experiments.

2. <u>Data Acquisition System</u>:

The US make Io tech Personal Daq/56 System is used to acquire online data at a suitable frequency. Figure (5) shows the photograph of this unit. The analog signal outputs are acquired into

Figure (5): Data Acquisition Personal Daq/56 System

PC through this daq hardware. This system was used for digitizing the analog data and communicating it to computer through USB port. The instrument is capable of acquiring data from a maximum of 20 different inputs, which could be from thermocouples, voltage, or both when used along with channel extension unit. The highest acquisition rate possible in Personal Daq is 50Hz. This corresponds to sampling rate duration of 12.5ms when acquiring data from a single channel. Sampling duration for each channel represents the integration time for that channel. The sampling duration has a direct bearing on sampling rate. If several channels are acquiring data, the acquisition rate is automatically adjusted to the maximum possible value based on sample duration and number of channels.

Personal Daq is a compact data acquisition device that makes the use of universal serial bus (USB). It can directly measure multiple channels of volts, thermocouple, pulse, frequency and digital I/O. The device can be located up to 5 meters from its host PC,allowing the unit to reside close to the point of measurement. No additional power supplies are required; except special set ups of multiple units. Currently two versions of this acquisition device are available, the Personal Daq/55 or Personal Daq/56. In addition there are two optional expansion modules, the PDQ1 and PDQ2.

3. Electronic Control System Components:

Figure (6) shows the electronic control system components fitted to the butterfly type control valve. Other than lambda sensor and lambda controller circuit, the components used in feedback control system are as follows:

1. Motor to convert the electronic signals into mechanical movement.
2. Limit Switches to limit the movement of butterfly type control valve.
3. Potentiometer to monitor and display the angle of movement of valve in volts.

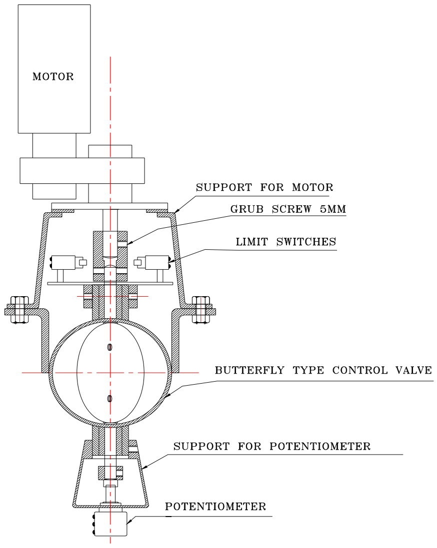


Figure (6): Electronic control system fixed to butterfly type control valve

3.1. Motor: The following are the specifications of the motor used in control system to move the control valve of the carburetion system.

Motor Specification:

Make: Precision Control
Input: 12 Volts DC
Speed: 3000 rpm
Gearing arrangement: Worm-wheel gearing
1^{st} – 3000 to 60 rpm, 2^{nd} – 60 to 1rpm

The motor is mounted on the top of carburetor control valve. Motor receives the signals from the controller and rotate in clockwise or counter clockwise depending on the mixture conditions.

3.2. Limit Switches: Two limit switches are used to limit the swing of control valve, one at close and other at full open position. These switches are required as a precautionary measure to stop the motor operation due to any fault; loose connections or short-circuit in controller circuit. A screw attached to motor coupling triggers the limit switches.

3.3. Potentiometer: A variable potentiometer, connected to the bottom is used to notice the movement of carburetor control valve. It gives the degree of valve movement in terms of voltage and the range of voltage is fixed between two limit switches. This voltage output can be further converted into percent opening or closing of control valve for the analysis of results.

4. <u>New Lambda Controller Circuit</u>: The lambda board or the engine controller is the heart of the control system. A basic block diagram of the lambda controller is shown in figure (7).

4.1) Sensor**:** The sensor being used is a heated lambda sensor. The lambda

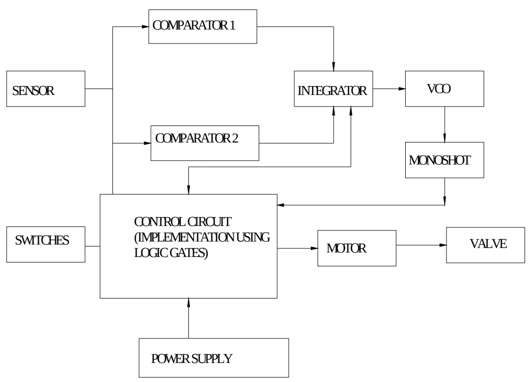


Figure (7): Lambda Controller Block Diagram

sensor is screwed into the exhaust system. The sensor works on the principle of potential difference, between two areas. The sensor gives a voltage signal to the board through an on board jumper, which represents an instantaneous composition of the air fuel mixture. There are two levels i.e. if the value of lambda exceeds one; A/F mixture is in lean condition, whereas if the lambda value drops below one; the A/F mixture is considered to be in rich condition. Depending upon the sensor values the board effectively open or close the control valve. The valve will be closed if the mixture is rich and vice versa.

Lambda is the symbol used to define the mixtures A/F ratio:

λ= (Instantaneous A/F ratio)/ (Stoichiometric A/F ratio)

Referred to the stoichiometric ratio λ = 1, a lean mixture ($\lambda > 1$) contains more air, and a rich mixture ($\lambda < 1$) contains less air. Heated or unheated lambda sensors are used depending upon exhaust system design and operating conditions.

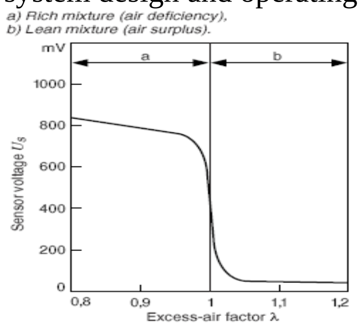


Figure (8): Voltage Characteristic of Lambda

4.2) Comparators**:** The output from the sensor is fed into the comparators. The fuel is considered to be rich if the sensor voltage exceeds 0.6 volts and lean when the sensor voltage falls below 0.2 volts.

Hence to determine the state of fuel by acting on the output given by the lambda sensor, comparators are used. The comparator is sometimes called as a voltage level detector.
There are two types of comparators namely:
1) Less than comparator
2) Greater than comparator

4.2.1) Less than Comparator: In a less than comparator the op amp will be driven to positive saturation if the input voltage goes lower than the reference voltage. The reference is fixed at 0.2 volts, hence lesser than comparator can be used to compare the sensor output as to whether it is lesser than 0.2 volts, which is the condition for fuel lean.

4.2.2) Greater than Comparator: In a greater than comparator the op amp will be driven to positive saturation if the input voltage goes greater than the reference voltage. The reference is fixed at 0.6 volts, hence greater than comparator can be used to compare the sensor output as to whether it is greater than 0.6 volts, which is the condition for fuel rich.

4.3) Integrators: Integrators are used to integrate the inputs given to them in a given period of time. Op-amp can be used to construct integrators. A basic integrator circuit consists of a capacitor connected to the non-inverting terminal with the other end grounded and the output shorted in feedback with the non-inverting input.

As the pulse widths of the comparator outputs vary the integrator gives the integrated values at the output. The integrator drives the voltage-controlled oscillator (VCO).

As the fuel remains rich or lean, varying pulse widths at the comparator outputs will mark it, the integrators will integrate these values and appropriate voltage levels will be used to drive the VCO.

4.4) Voltage Controlled Oscillator: The voltage output of the comparator is connected to a square waveform of equivalent frequency.

4.5) Monoshot: The waveform produced by the VCO is used to produce pulses, which controls the rate at which the wave moves. Varying the resistor, determining the pulse width of the output, the monoshot can also vary the rate.

EXPERIMENTAL PROCEDURE

The procedure involved in carrying out the experiment is as described below:

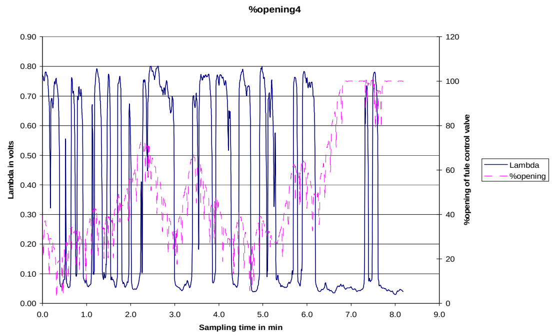
1. Top the gasifier with available biomass.
2. Switch on the cooling system and scrubber motor for water circulation.
3. Start the gasifier blower with partial valve opening.
4. Flare / ignite the biomass through the air nozzles.
5. After 10 minutes, check the oxygen percentage in the gas being generated.
6. At oxygen values near 2%, try to flare the jet type burner.
7. After the burner gets ignited, wait for 20-30 minutes for gasifier stabilization.
8. Start the suction blower while keeping the gas line ball valve fully closed and air side valve opened.

9. Set the post blower mixture control valve for required flow rates.
10. Insert a burning cotton wick inside the burner shell and hold it near the burner tip.
11. Keeping the control valve closed where the control system motor is mounted, open the ball valve partly.
12. Switch on the lambda controller circuit and put it in manual mode.
13. Slowly try to open the control valve using the control system till the air-gas mixture gets ignited.
14. Adjust the ball valve in the gas line and the control valve together such that the control valve position is at its midway and ensure the mixture burns in a stable manner.
15. Put the closed loop control system in automatic mode.
16. Start the data acquisition system to record lambda and potentiometer values in volts.

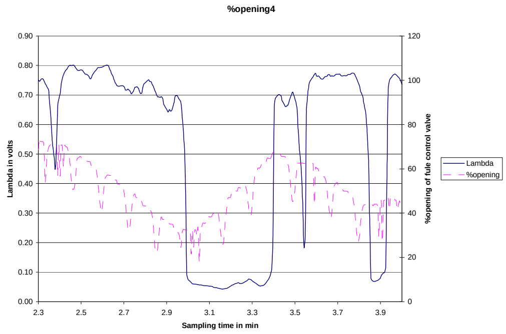
RESULTS

The results of the few experiments are shown here in a graphical form. For particular time period the readings were taken. The time, lambda signal and potentiometer readings have been acquired on a DAQ system. The potentiometer voltage values are converted into percentage opening of the throttle valve. Fig from (9) to (11) shows the plot of time versus lambda volts and % opening of the valve.

It can be seen from the figures that there is a transition from lean to rich and vice versa as per the lambda values above 0.6 and below 0.2 V respectively. It can also be seen that time taken for this transition



(a) For 9 min

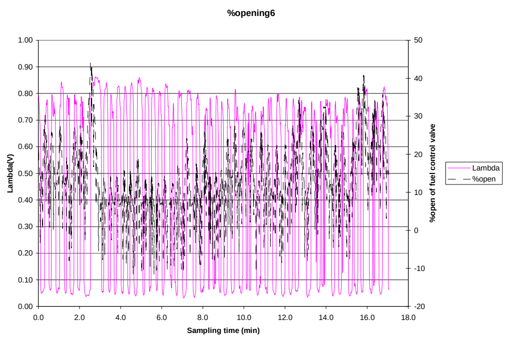


(b**)** Amplified between 2.3 and 4 min

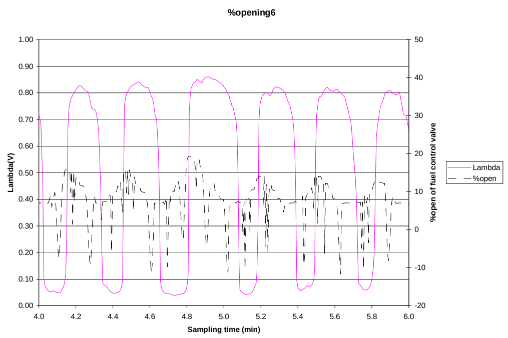
Fig (9) Response of feedback control system

is varying. This variations could be attributed to instability of the flame inside the burner, the flow characteristic during opening and closing conditions, intermittent cooling of the burner and finally due to the gas floe pressure.

The transition of the mixture being very rapid, it is seen that a fluctuating air fuel ratio is obtained rather than the constant

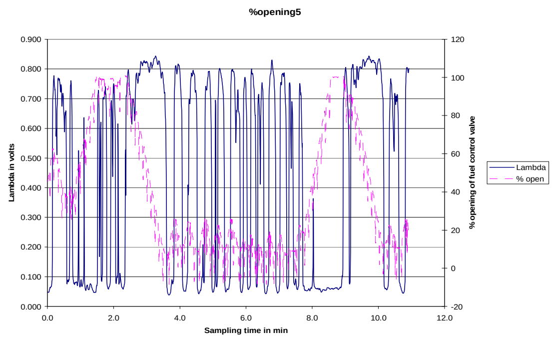


(a) For 18 min.

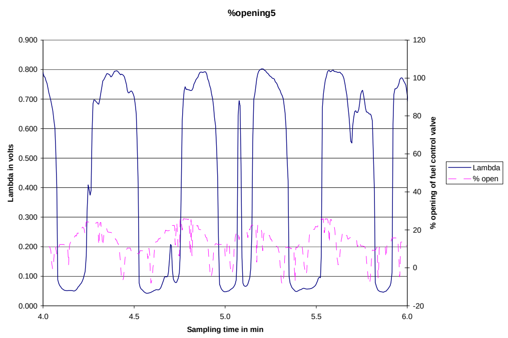


(b**)** Amplified between 4 and 6 min.

Fig (10) Response of feedback control system



(a) For 12 min.



(b) Amplified between 4 and 6 min.

Fig (11) Response of feedback control system

air fuel ratio with no response in between 0.2 -0.6 V.

It can be seen that the lambda variations are in same range. But this is not true for the control valve. The control valve opening varies to different degree to cause same change in the lambda. This could be attributed to the fact that there could be some other factors which are causing the change in the air fuel ratio.

CONCLUSIONS

The extensive experimentation with the engine simulating conditions the design of the control and actuation parts with the use of lambda sensor is found to be working suitably. So with the use of feedback control system, the lambda sensor based carburetor can provide stoichiometric air fuel ratio and will help in reducing backfiring problem faced during frequent load changes and throw off conditions. Time lag is the inbuilt phenomenon with feedback control systems, which can be minimized by ensuring minimum distance between the sensing and actuating points.

REFERENCES

1. ABETS, IISc, *Bangalore, Biomass to energy,* 2003
2. G.Sridhar, NKS Rajan, H.S.Mukunda et al, *Development of producer gas engines,* Communicated to International Journal of Engine Research.
3. Santosh G. Taji, *Design and Testing of Carburetor for Producer Gas Application,* M.E. Dissertation, 2002.
4. Dighade P.K., *Tuning of producer gas carburetor for frequent load changes and throw –off condition using electronic control system*, ME thesis, 2004.
5. Heywood, J.B**.**, *Internal Combustion Engine Fundamentals*, International Edition, New York: McGraw Hill Company, 1988.