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# EXPERIMENTAL STUDY OF BIOGAS OPERATED POROUS RADIANT BURNER FOR DOMESTIC APPLICATION

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***Abstract:* Biogas is a kind of bio-fuel that occurs naturally as a result of the decomposition of organic waste. When organic matter, including food waste and animal waste, decomposes in an anaerobic (oxygen-free) environment, it releases a gas mixture, mainly methane (50-80%) and carbon dioxide (20-50%).This document describes the combustion behavior of home-made Porous Radiant Burner (PRB) used in industrial crematoryas well as bio-medical solid waste dumped systems. PRB is mainly designed to work in the range of 5-10 kW firing rate, which is a two sided -layer porous environment technique. Three kinds of burners namely convergent (60mm), straight (70mm), and divergent (80mm) are considered for experiment. The burner contains two zones (i) combustion zone, and (ii) pre-heating zone. Sic foam of 10 ppi with 25mm stiffness and steel balls (6.5 mm each) acts as combustion zone and pre-heating zone respectively.From experiments, better efficiency is attained using the newly designed PRB.This is performed by varying the equivalence ratio ($\phi$) between 0.10 and 0.60 in a constant operating range.The 59.92% burner operating range is the maximum efficiency analyzed for a PRB with a diameter of 80 mm and a 0.16 equivalent ratio of 0.55 kW.***

***Keywords:* Porous, Radiant Burner, Biogas, Conventional Burner, Thermal efficiency**

## 1. Introduction

The current social and economic environmental scenarios require access to reliable, affordable and clean energy to meet all basic requirements of human being [1]. Limited sources of fossil fuels and environmental pollution are the biggest obstacles to attain these goals. Therefore, it is required to improve the energy supply as renewable energy sources to maintain rapid urbanization and a minimum standard of living for millions of Indian families (Figure 1).

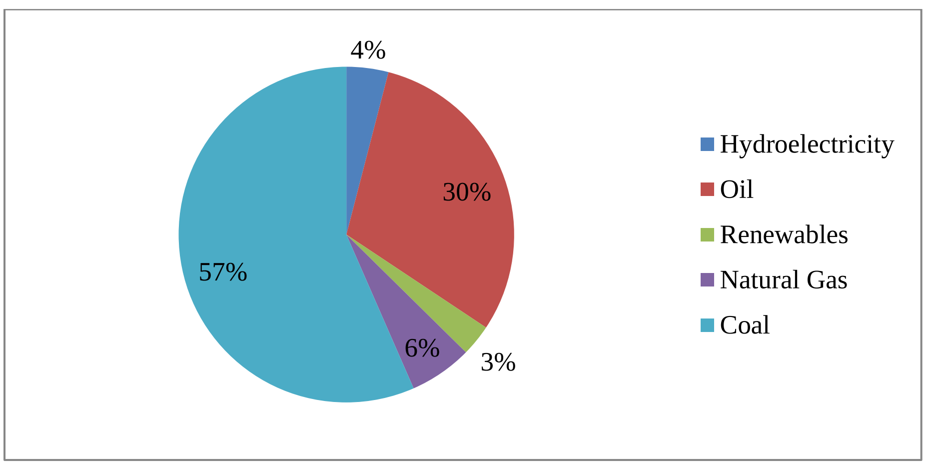


Figure 1: Energy graph of India [2]

Renewable energy sources play a vital role in the energy network of future trend. Presently, there are four major areas where renewable energy sources can be used that are transportation, home, commercial, and power generation. The motive of Ministry of New and Renewable Energy (MNRE) in India is toprovide facilities to the end users with a number of renewable energy based programs. Applications including home and profit-making applications used by large organizations are the two main centre of attention of MNRE. MNRE is also focusing on the use of renewable energy at a lower rate and the search for alternative fuels [3]. MNRE is extremelydevoted to promote the use of biogas by planning programs such as the National Biogas and Fertilizer Management Program (NBMMP) and the Biogas Power (Non-Network) Generation Program.The main motive of MNRE is to design biogas plants using cattle dung and using other recyclable wastes as shown in Figure 2 [4]. The prepared biogas is helpful to solve multiple purposes like cooking, generating electricity that can be supplied to nearby people of rural areas. An example of biogas applications is shown in Figure 2.

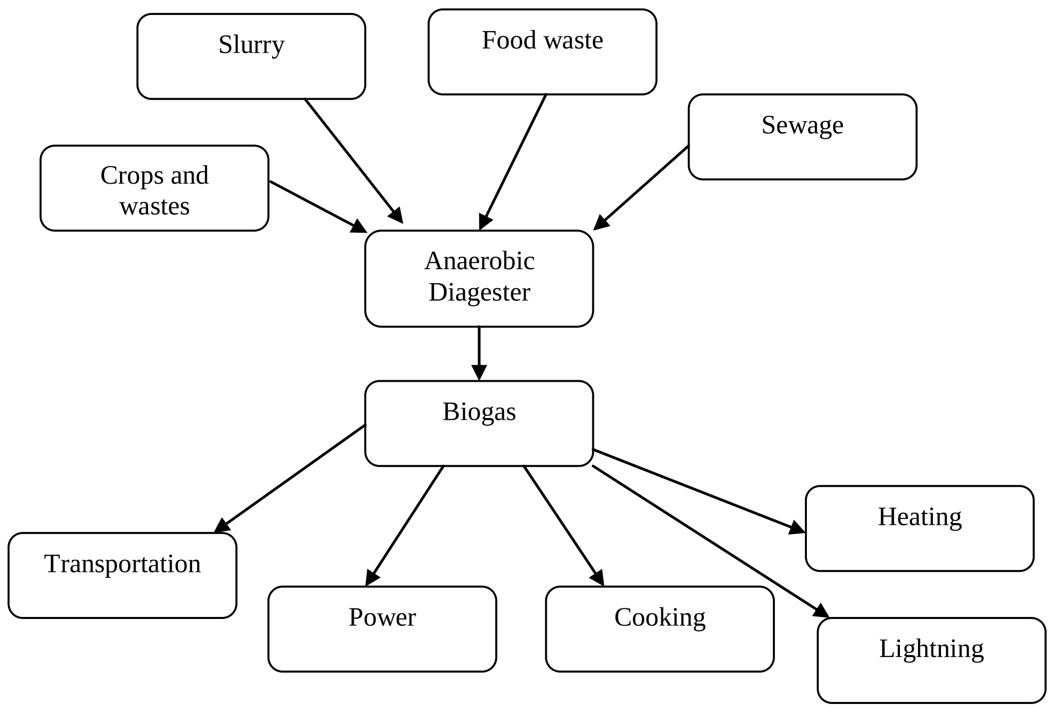


Figure 2 Biogas sources and applications

Cooking is considered as one of the most frequently used application of biogas, in which biogas is found as cost-effective fuel in the last few decades. However, due to the shortage of awell-organized and environmentally friendly burner, the utilization of biogas as a fuel in cooking for both home and other applications is discontinued.

In this research, experiments have been performed on Porous Radiant Burner (PRB) with different diameters. The quality enhancement process of biogas burners is very costly and results in unproductive combustion while operated in free flame mode. A number of researchers [5-8] have conducted experiments using different fuels while testing usability of fuels. Ignition of biogas in porous material is a suitable alternative to take out its full potential. By utilizing the advantages of porous material that its heat can be recalculated, a suitable platform to ignite Low calorific value Gas (LCG) can be performed. PRB has unique heat transformation mechanism and hence it is unique from the conventional burners. PRB has features like flame is controllable and transfer heat with radioactive property.

The rest of the work is organized as section 2 presents the research performed by existing researchers. In section 3, proposed work is presented. Section 4 describes the result and discussion of the proposed model. The conclusion and the key points of the work are mentioned in section 5.

## 2. Related work

This section discussed about the related work performed by a number of researchers to determine the efficiency of PRB using biogas.

**Gao et al. (2011)** have investigated biogas combustion at distinct Carbon Dioxide ($CO_2$) using 2-layer packed bed burner. At different $CO_2$ dilution, flame stability has been attained. From tests it has been observed that the flame speed has been stabilized for biogas compared to the pure $CH_4$. The obtained stable flame for biogas has results to higher level. The equivalent ratio has been determined as in direct relation to flame temperature. The location of flame has been moved down with the increase in the flame speed.Compared to pure $CH_4$, the concentration of NOx was determined down to 12 ppm [9].

**Keramiotis and Founti (2013)** have presented a comprehensive study to determine the efficiency and pollutant emission of PRB using biogas mixture. Rectangular shape 2-layer porous burner with flame trap of Al2O3 has been used using SiSiC foam of 10 pores per inch (ppi). The input to the burner has been given in 60:40 ratio of methane: $CO_2$. Stability analysis has been performed to determine the scope of operation in the form of thermal load and ratio of mixture equivalence. With the help of thermocouple and infrared thermography, gas and solid phases has been measured. The quantification of gas emission has been examined using online gas analyzer sampling system as well as using gas chromatographer. The results shows higher load stability and lower hydrocarbon emission [10].

**Jadhav and Sudhakar (2015)**have tried to design a suitable biogas based burner for domestic applications. To obtain maximum efficiency from the burner best designing of burner is needed. The best design of burner includes, dimension, burner holes size, number of holes, appropriate mixing of fuel and air, and the flow rate of fuel.The simulation has been performed using biogas burner with the help of computational fluid dynamics and applied Genetic Algorithm (GA) to optimize the prepared burner model. The results show that designed burner is more efficient and surpasses the results from other exiting works without wasting biogas. The technique is cheaper and can be beneficial for poor people of urban as well as rural areas [11].

**Devi et al. (2019)** have presented combustion behavior of PRB for in house application as well as for industries application. A PRB, which was operated (5 to 10 KW) of firing rate has been developed using 2-layer porous technology. Two layers are made up of Silicon Carbide (SiC) that behave like combustion and alumina (Al2O3) that acts as preheat element. The performance of the designed PRB has been examined in terms of emission characteristics and combustion efficacy. The performance has been analysed by varying the firing rate from 5 to 10 KW, equivalence ration surrounded by constant operating range (0.75 to 0.97). From experiment it has been concluded that pollution using designed PRB are very small in contrast to the traditional one. Results indicated that combustion efficiency has been decreased by 95 % from CO and 85 % by NOx values using biogas based combustion PRB [12].

**Habib et al. (2020)**have presented a biogas based burner and examined the effect by varying flow rate as well as chemical composition. The considered porous burner has consists of Sic layers positioned inside a tube made up of quartz. The PRB is equipped with a set of axially connected thermocouples and image has been captured using digital camera.Mixture of methane and CO2, individual methane are mixed with CO2 and then inputted to the burner with an equal ration less than 0.3. Programmable mass flow has been used to monitor the flue rate by passing sin wave with dynamic voltage and frequency. From the collected images it has been analyzed that the imposed disturbance created motion in the flame of considered PRB. The disturbance has been measured for both biogas and methane. The results reveal that higher variation has been seen for methane compared to biogas [13].

## 3. Proposed Work

For experiment, PRB is used in this research work. Fuel and air rate has been calculated using rotameter device. The air is passed through Y- shaped nozzle and mixed up with fuel at steel chamber. After mixing, it extends to the combustion zone for ignition as shown in Figure 3. The burner contains two zones (i) combustion zone, and (ii) pre-heating zone. Sic foam of 10 ppi with 25mm stiffness and steel balls (6.5 mm each) acts as combustion zone and pre-heating zone respectively.

High temperature resistive material is used to cast the body of PRB. The biogas is taken from the plant and fed through nozzle to the burner. The setup included control valve that is used to control the supply of the gas fed to the burner in a regular way. The characteristics of the Conventional Burner (CB) and the PRB used in proposed design are given in Table 1.

Table 1 Properties of designed biogas based PRB

| Elements | Specifications |
|---|---|
| CB | Commercial/ domestic burner |
| PRB | 60, 70 and 80 mm of diameter |
| Porous insert | Sic→10 ppi with 25mm stiffness<br>Steelbar→6.5 mm each |

The air supply system has includes compressor, control valve, and Rota meter. The mixing of biogas and air has been performed by equipping an additional pipe at the bottom of chamber. The schematic diagram of the experimental setup is shown in Figure 3.

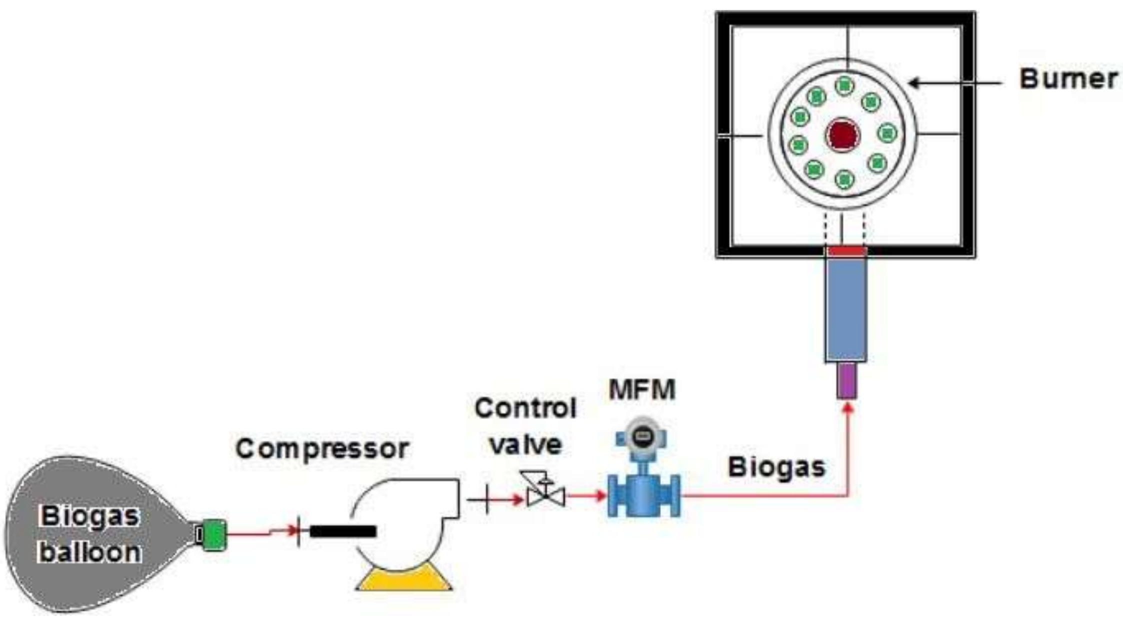


Figure 3: Schematic Diagram for Biogas supply line

To determine the efficiency of the PRB combustion with biogas, Water Boiling Test (WBT) has been performed. An aluminum pan of (0.5 to 1 Kg) with lid has been taken as per IS 8749:2002. The pan is filled with 1 litter of water at room temperature (20 to 22 degree Celsius). The initial temperature (T1) was measured using thermometer by inserting into the water pan. Then the pan is put on the PRB stove, and boiled water until the temperature reached up to 90 degree Celsius. Temperature (T2) that is final temperature was noted down. Now, PRB stove was switched off. The time while the pan is placed on the stove and when the stove is switched off is noted. To check the efficiency, the experiments have been taken at least 3 to 4 times and noted down the time for every iteration. Also, the initial weight of pan with water and final weight of pan with water has also been noted down. The thermal efficiency of the considered PRB is calculated using equation (1).

$$\eta_{th} = \frac{(M_p+M_w)\times(T_2-T_1)}{M_b\times LCV} \quad (1)$$

Where,

$M_p$→Mass of pan

$M_w$→ Mass of water

$T_2$→ Final temperature

$T_1$→ Initial temperature

$M_b$→mass of biogas

LCV→ mass of flow rate

Part of the air-to-fuel ratio refers to the fuel consumption for the actual combustion rate of the air used to increase the actual water temperature. Using a rotameter, the air flow is calculated, and at the same time we can get the degree of actual air used for ignition and help to measure the fuel with the help of weight balance.

## 4. Result and discussion

As per the process of working discussed above, equivalence ratio at which the PRB flame is operated is determined in the range (0.10 to 0.60). The measurement of temperature distribution and adaptability of domestic as well as PRB is discussed in this section.

The distribution of temperature on the PRB has been measured on the basis of following parameters.

i). Equivalence ratio
ii). Air flow ratio

### *4.1 Temperature Distribution*

The temperature of both CB and PRB has been measured using K-type thermocouple. The output of which has been taken using Data Acquisition System (DAS). The maximum time of operation of burner has been considered as 70 minutes. The temperature at different time instance with the variation of 10 minutes has been observed at different equivalence ratio.

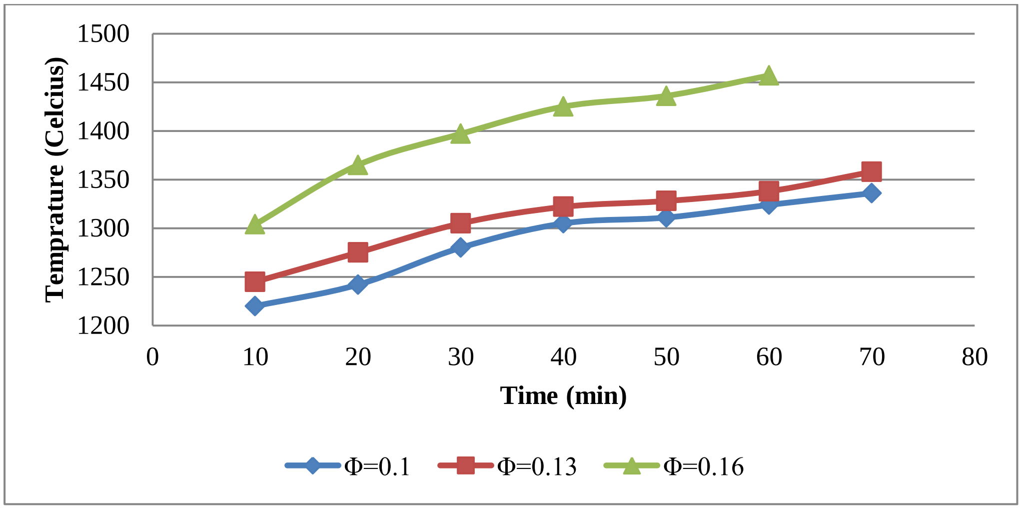


Figure 4: Temperature vs Time graph for PRB (80mm) at different (∅) for convergent

From the above graph shown in Figure 4, maximum temperature has been attained after 70 minutes of burner combustion for all three equivalence ratio. The maximum temperature observed at∅=0.1, ∅=0.13, and ∅=0.16 has been examined as 1336°C, 1358°C, and 1479°C respectively.

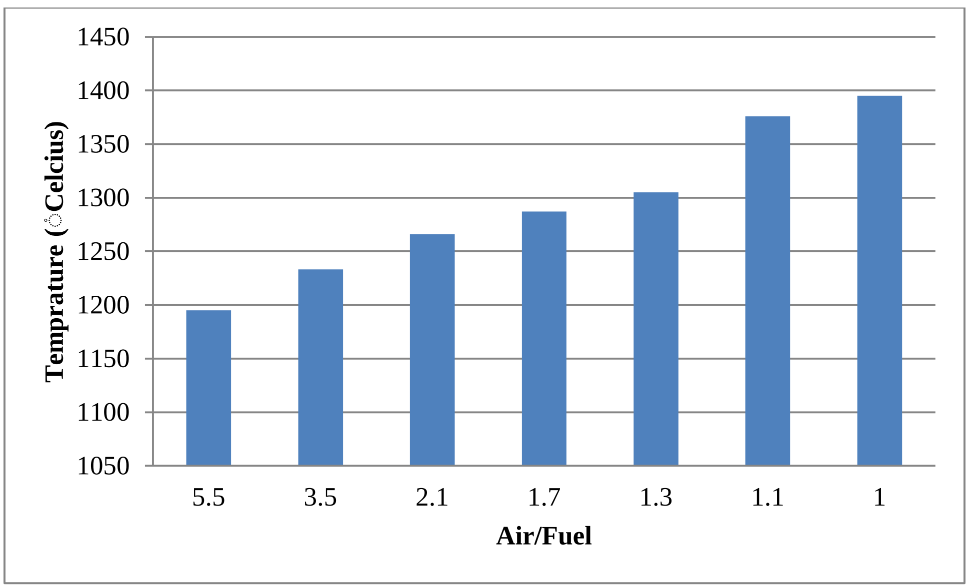


Figure 5: Temperature vs Air/fuel of PRB 80mm of Convergent

The graph shown in Figure 5 represents the variation of temperature by varying air/fuel ratio for 80 mm diameter burner. With the decrease in air fuel ratio, the temperature of the burner goes on increases. The maximum and minimum temperature of 1395 degree Celsius, and 1195 degree Celsius has been obtained at air/fuel ratio of 1.0 and 5.5 respectively.

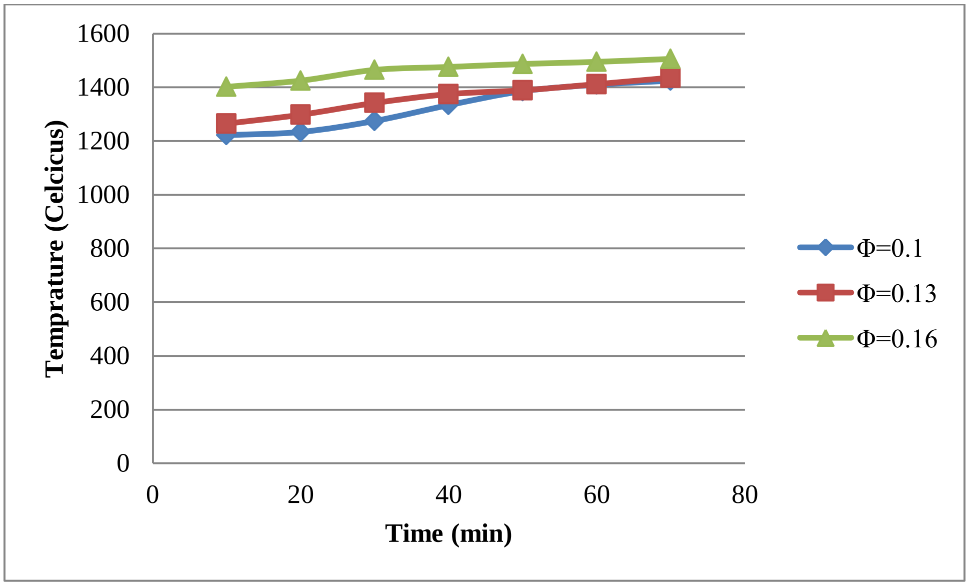


Figure 6: Temperature vs Time graph for PRB (70 mm) at different (∅) for Divergent

The variation of temperature with respect time by varying equivalence angle is shown in Figure 6. Figure shows that with the increase in time the temperature of burner also increase and become maximum at time= 70 mint. The maximum temperature observed at ∅=0.1, ∅=0.13, and ∅=0.16 has been examined as 1425°C, 1436°C, and 1506°C respectively.

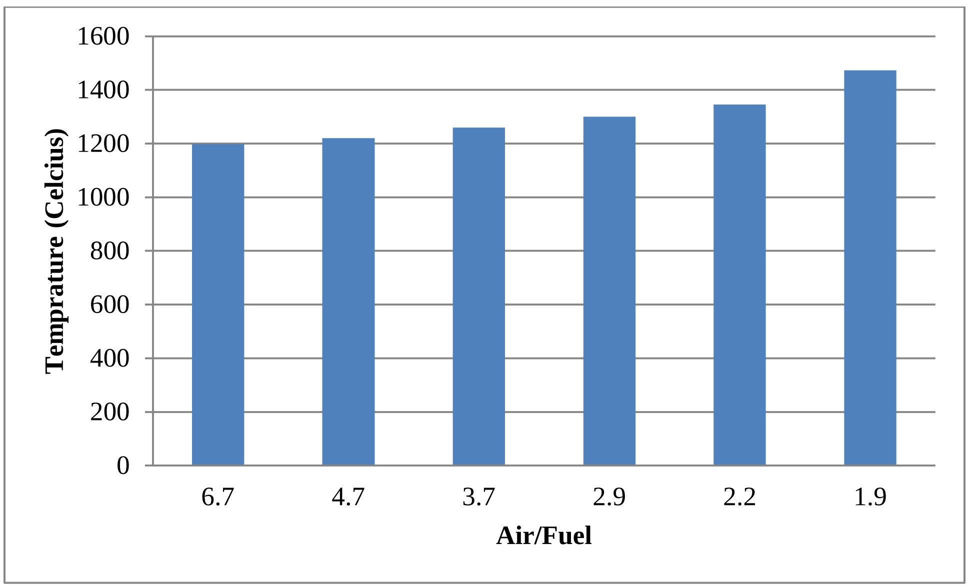


Figure 7: Temperature vs Air/fuel of PRB 70mm of divergent

The variation of temperature using 70mm divergent PRB with respect to air/fuel ration has been depicted in Figure 7. From the graph it has been observed that, the temperature is increased from 1198 °C to 1473°C with the reduction fuel from 6.7 to 1.9 respectively.

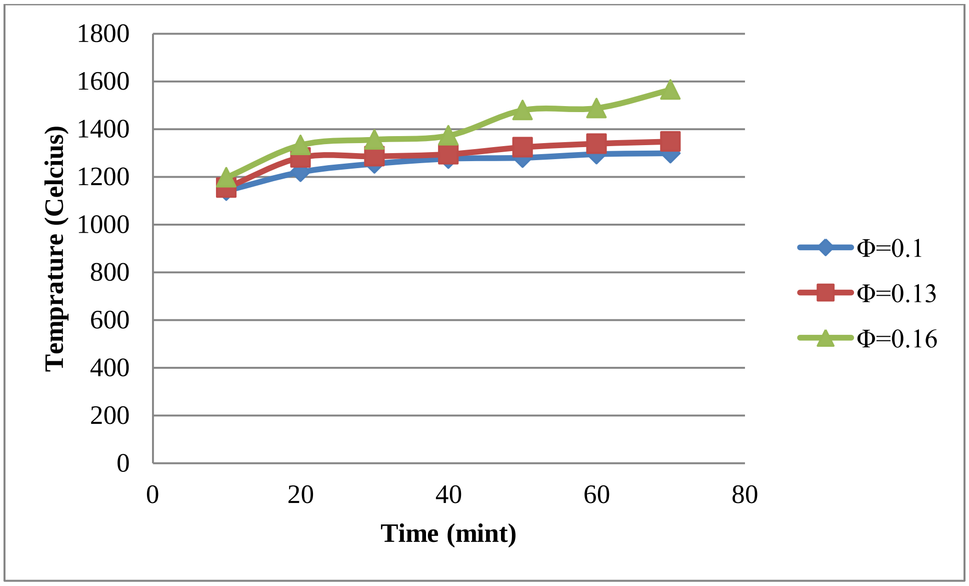


Figure 8: Temperature vs Time graph for PRB (60 mm) at different (Ø) for Straight

The examined temperature of straight PRB measured using K-type of thermocouple with respect to time is shown in Figure 8. The temperature has been observed for different equivalence ration (Ø=0.1, Ø=0.13, and Ø=0.16). The blue, the red and the green line represents the temperature observed at constant Ø=0.1, Ø=0.13, and Ø=0.16 respectively. At Ø=0.16, maximum temperature of 1565 °C has been observed at time t=70 min.

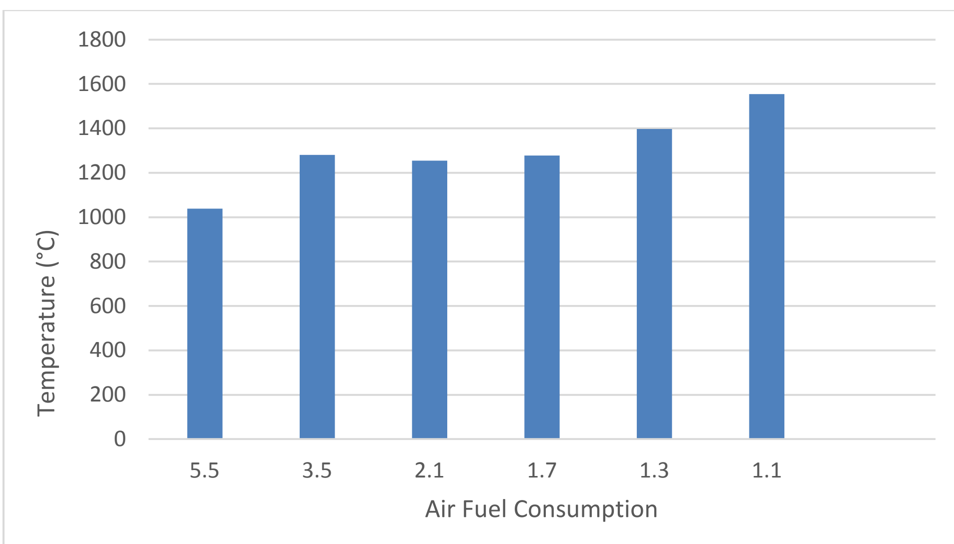


Figure 9: Temperature vs Air/fuel of PRB 60mm of Straight burner

Figure 9 represents the variation of temperature with respect to air/fuel ratio. For straight burner with diameter of 60mm, maximum temperature is obtained at 1 f/sec air/fuel ratio.

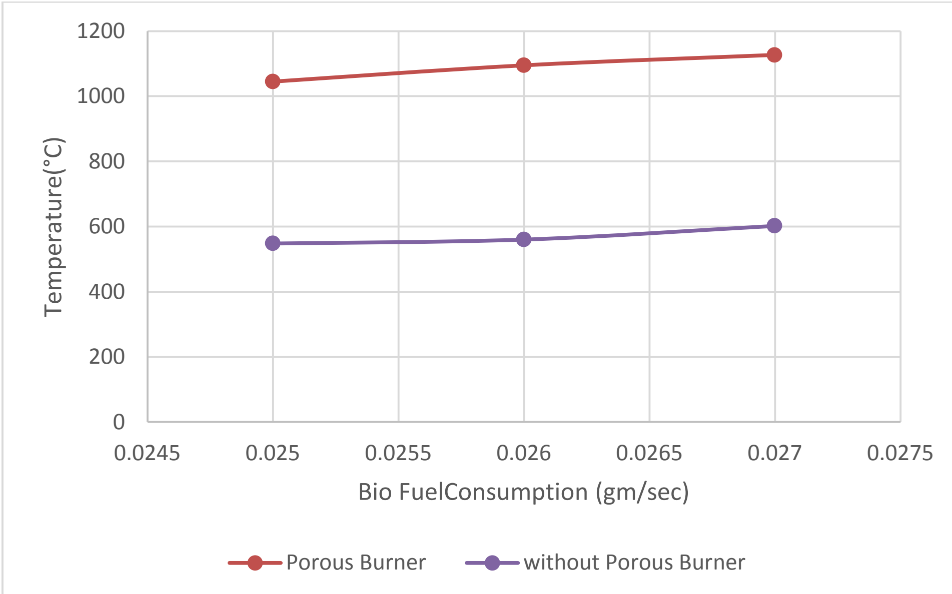


Figure 10: Temperature vs Fuel Consumption (With and Without Porous Burner)

The variation of raise in temperature with PRB and without PRB using biogas with different biogas consumption has been presented in Figure 10. To attain maximum temperature for PRB, and without PRB, maximum bio fuel has been consumed as 0.27 gm/sec and attained temperature of 1127 degree Celsius, and 602 degree Celsius respectively.

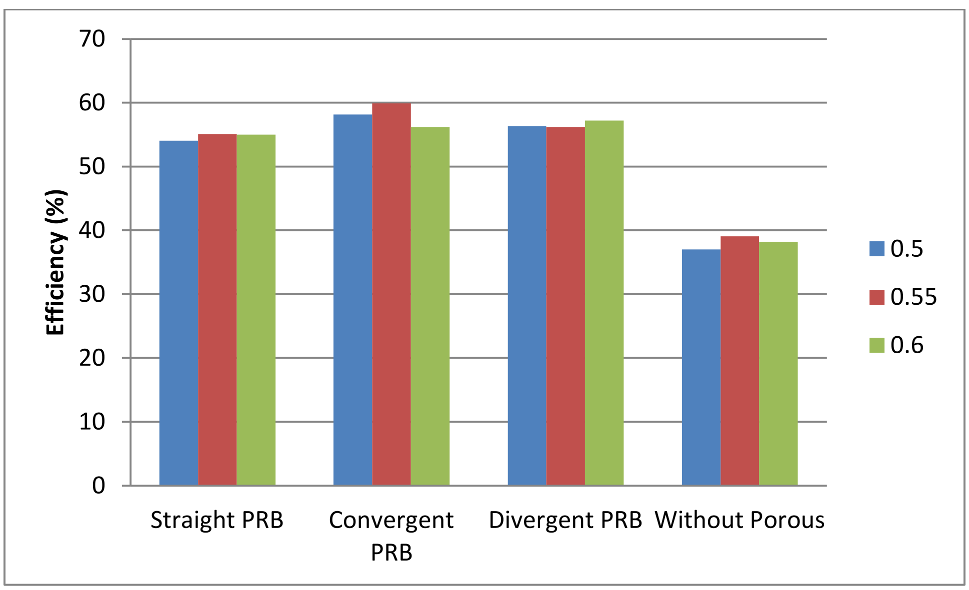


Figure 11: Efficiency of burner (with and without porous)

Figure 11 represents the thermal efficiency examined during experiment performed on four different types of burners namely straight PRB, convergent PRB, divergent PRB and normal commercial burner. From the figure it is clearly observed that maximum efficiency has been observed for convergent PRB with 0.55 KW of power. Also, for 80 mm diameter burner with convergent PRB shows maximum efficiency compared to other two PRB as well as without porous burner. At power =0.55 KW, the increase in efficiency of convergent PRB of 8.73% and 6.62 % has been attained compared to straight PRB and divergent PRB respectively. Also, in contrast to without porous burner, the increase in efficiency using straight convergent, and divergent porous burner at power 0.55 KW has been attained as 29.12%, 34.81%, and 30.5 % respectively.

## 5. Conclusion

This paper presents biogas based combustion in a PRB designed as a substitute to a conventional burner (CB). The operation of designed PRB has been stabilized within equivalence ratio of 0.1 to 0.60.

- Maximum of 60 % thermal efficiency has been attained with convergent PRB.
- AT power =0.55 KW, the increase in efficiency of convergent PRB of 8.73% and 6.62 % has been attained compared to straight PRB and divergent PRB respectively.
- Also, in contrast to without porous burner, the increase in efficiency using straight convergent, and divergent porous burner at power 0.55 KW has been attained as 29.12%, 34.81%, and 30.5 % respectively.
- Maximum temperature for PRB and without PRB of 1127 degree Celsius, and 602 degree Celsius has been obtained at maximum bio fuel consumption of 0.27 gm/sec.
- Maximum temperature of (1565) at Ø=0.16 has been observed for straight burner at diameter of 80 mm.

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