# THE DEVELOPMENT OF AN EFFICIENT COMBUSTION SYSTEM THAT FIRES BIO-FUELS, FOR USE IN RURAL AREAS OF THE PHILIPPINES

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## ABSTRACT

This paper details the research and development of an efficient burner system, operating on *biogas*, for use in remote or rural regions of developing countries such as the Philippines. A desirable use for such a system in these areas is domestic cooking, and the burner has been designed with this need in mind, focusing on characteristics such as simplicity, cost effectiveness, efficiency and safety. This report discusses the aims of the project, and how each was achieved or evaluated. The required specifications and cost analyses are examined along with the design and availability of existing systems. Also discussed are the modifications necessary to meet the project requirements, and the testing involved in determining the performance of each suggested burner system.

**KEYWORDS:** Biogas, methane, burner, Philippines.

## 1. INTRODUCTION

### 1.1 Roseworthy Digester

Paul Harris and the Department of Agronomy & Farming Systems at Adelaide University's Roseworthy campus has developed a simple, plug flow digester that generates *biogas* – consisting predominantly of methane and carbon dioxide – through the anaerobic decomposition of animal or vegetable waste material. Because of its small, simple, and inexpensive design, such a digester can be installed with little technical understanding, and on a limited budget. Furthermore, the gas produced is a useful, inexpensive and renewable energy source.

Constructed from basic materials such as PVC piping and a polyethylene bag, this type of bio-digester holds great appeal to those living in remote rural or under-developed areas. The digester is approximately 2 m long and 0.8 m in diameter [5]. Only preliminary calculations have been conducted and as such, more technical performance data calculations must be made. Currently the biogas produced is being stored in a tractor tyre tube. To date, a suitable burner has yet to be developed for this system, and there have been some difficulties in trying to maintain a steady flame for gases with relatively low proportions of methane (~40%) [5].

### 1.2 Combustion of Biogas

The combustion of biogas produces a hot, clean flame that does not dirty pots or irritates the eyes, as does the smoke from other fuels. Biogas has a wide range of different uses – it can be burnt directly as a fuel for cooking, lighting, heating, water pumping, or grain milling, and it can be used to fuel combustion engines. In larger applications where scale and skills warrant, biogas can be pressurized and stored, cleaned for sale to commercial gas suppliers, or converted to electricity and sold to power grids, to meet peak energy needs.

Although biogas generation has been utilized since the 1950's, and the principles of digestion are well documented, little is known about the burning of such gases. This is due to the complex nature of methane, and difficulties associated in getting it to burn. In most cases, burners are developed using a 'trial-and-error' process, rather than consulting a text, or applying a formula.

There are many different designs of biogas burner available. Figure 1 illustrates the different aspects of a burner that have to be considered when it is being designed or when different burner designs are compared.

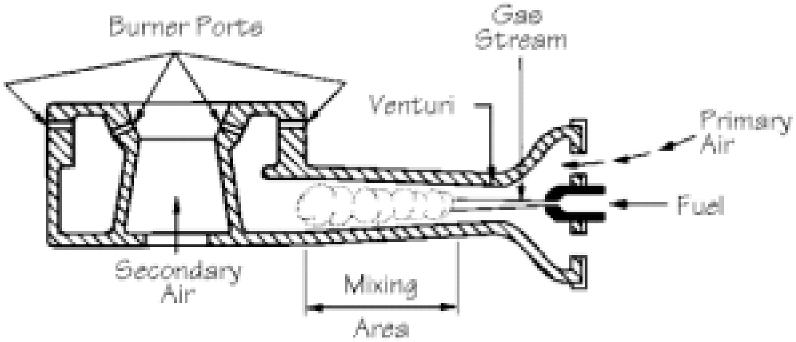


**Figure 1** – Example of a pre-mixed domestic cooker

A burner mixes gas and air in the correct proportion and feeds the mixture to a burner head, which supports the flame under the vessel to be heated. The flow of gas into the burner is controlled by the size of the main jet, as well as the gas pressure.

### 1.3 Demands for Biogas in Developing Countries

Developing countries cannot afford to provide reliable mainstream energy sources such as electricity or natural gas to the domestic user, nor do they have the funds to invest in alternative sources of energy such as solar, wind, hydroelectric or geothermal power. Hence, there is growing interest in the application of biogas in these areas. Smith [3] concludes that *biomass* (the waste material that is used to produce biogas) is "the single most important source of energy" among developing countries, especially within the domestic sector. The main use for biomass is in household cooking, with wood representing the major energy source. The present use of wood is contributing to the serious problem of deforestation around the globe, forcing governments to seek cheap and available alternatives [3].

Not only do the gases produced by digesters have many uses, but the by-product – sludge – is also a good fertilizer. Considering that the majority of such countries are rural regions with access to a regular supply of vegetable and animal wastes, this sludge fertilizer is a valuable derivative of such systems.

Therefore, biogas is an important part of the solution to the energy crisis faced by developing countries. Not only does it provide a cheap, readily available and renewable energy source, but also a valuable fertilizer to primarily rural regions. Using biogas as an alternative reduces the need to deplete surrounding forest areas, while improving the treatment of waste by breaking it down into less harmful components.

## 2. AIMS

This project aims to develop a domestic cooking system for developing countries that is simple, efficient and inexpensive. As such, this project strives to improve the standard of living in these areas by offering a system that effectively utilises a cheap, readily available and renewable energy source – *biogas*. Hence, it is also an objective of this project to provide the means by which people in these areas can save time and money while improving their measure of health. More specifically, for the burner system the project aims to

- Develop a technical specification
- Determine an appropriate cost
- Select commonly available cookers that can be easily modified
- Design a cost-effective modification; and
- Test the modified system

## 3. SPECIFICATIONS

According to the 1995 Household Energy Consumption Survey (HECS), a high percentage of LPG, firewood and biomass residue fuels are used for cooking in rural areas of the Philippines (99.8, 99.9 and 87.3 percent respectively) [4]. In poorer islands such as Eastern Samar, firewood represents the main source of energy for cooking or preparing food, and is collected from surrounding forests and scrub. This is due to the high cost and unsteady supply of electricity to these regions, as well as the low availability and inconvenience of LPG bottles. The two main reasons given by Filipinos for switching to alternative fuels is *convenience* and *availability* [4]. Although other uses for biogas include generating electricity and providing lighting, the most beneficial application for these areas is in domestic cooking.

The average family size in the Eastern Visayas region of the Philippines (of which Samar is a part) is 5.14 persons per household, but for poorer families this number increases to 6 persons per household [4]. In general, each home consists of 2-3 adults and 3-4 children [5]. The typical food consumed by people living in rural areas of the Philippines is rice and fish. Rice is cooked in deep aluminium pots placed over an open fire, while fish is normally placed directly onto the remaining hot coals. Regular meals are cooked in a single ¾ - 1-hour session, and then eaten cold over the remainder of the day [5].

On average, each family owns one or two pigs, and every second family has chickens [4]. According to Fulford [1] this amounts to a minimum supply of approximately 280 litres of biogas per day, for a digester similar to that designed at Roseworthy, assuming that the manure from only one pig is available. The average temperature throughout the year ranges from 28° to 32°Celsius, and it rains two out of three days [5].

The general population of rural areas such as Eastern Samar does not have a basic understanding of science [5]. Hence, the physical, chemical and environmental aspects of anaerobic digestion, and the combustion of methane that are at the heart of this project will not be grasped by the majority of people that will be using such technology. This is a cause for concern when dealing with the installation and maintenance of any proposed biogas system.

The proposed combustion system must meet the requirements specified by the consumer, namely those living in rural regions of the Philippines. Firstly, it must provide a means of utilising the biogas to cook for a minimum of six people, for a period of not less than one hour each day. The burner must be designed such that sufficient heat is supplied to cook the required amount of food, at a rate that does not exceed the 280 litres of Furthermore, the system must be able to operate under the climate conditions stated previously. biogas produced each day. The burner must be of simple design that allows for easy installation and maintenance with little technical know-how, such that the convenience and availability of biogas as an energy source is increased. It is also important that the burner is cost effective, in order to remain a viable alternative cooking method for people living in rural regions of the Philippine islands.

## 4. COST ANALYSIS

In 1999, there were reportedly 14.7 million families in the Philippines. On the average, each family earned 60,788 Philippine Pesos at current prices over a six-month period. Expenditures, on the other hand, amounted to 52,014 Pesos at current prices for the same period [4]. At the time of writing, the Australian Dollar is equivalent to 26.66 Philippine Pesos. This indicates that the average Filipino is capable of saving approximately AUS$701.92 annually. This figure would be lower for poorer families, or those living in rural areas, as they fall into the lower 40% of families that earned only 11.2 percent of the total income over the six-month period in 1999 [4].

The materials needed in the construction of the digester designed at Roseworthy are estimated to cost approximately AUS$40-60 [5], whilst many existing designs of simple, cast-iron burners are available from camping and hardware stores in Australia for around AUS$15-30 [7]. Therefore, the total cost for the digester and combustion system will be roughly AUS$70-90, which represents 10 – 15% of the average family's savings for an entire year (or possibly 30-50% for poorer families).

This project aims to keep costs as low as possible whilst maintaining efficiency in a simple design. It is the opinion of this design team that it will be more cost effective to modify an existing burner design that is widely available and mass produced, rather than to design and build a new burner system from new materials for a specific market. Therefore, existing systems must be selected and appropriate modifications made, such that efficiency is increased without adding incredibly to the cost.

## 5. EXISTING SYSTEMS

As stated previously, many burner designs exist and are available from camping and hardware stores, as well as a number of different wholesalers. These have been designed to operate on either LPG or natural gas, and are usually constructed from cast-iron (although stainless steel and aluminium designs exist, but are expensive by comparison). All have standard, universal fittings, and have been designed to operate under a range of outdoor conditions. These systems also allow for the mounting of various sizes of pots and pans over the flame [7].

Individual systems really only vary on the number of burner ports, the size of the mixing area (which affects how much primary air is added), inlet port size, calorific value ($MJ/m^3$) and gas consumption (kg/h). For this project, it has been estimated that the required calorific value for a generated gas with 40% methane will be around 15 $MJ/m^3$. Therefore a calorific range of 10 to 20 MJ/hour in burners is desirable to allow for varying compositions of biogas. Therefore, a number of burners with different ratings have been purchased and modified, and must undergo testing to determine which combination of gas flow rate, inlet pressure and burner port diameter is the most efficient.

## 6. MODIFICATIONS

Primarily, once the required heating value has been determined, adjustments can be made to the inlet jet diameter as well as the flow rate of the gas according to varying composition of biogas for each burner of specific calorific rating. Before searching for solutions and designing a system for our target family to cook with, we need to consider what their requirements are. The main meal for the families in question is fish and rice. From calculations, it has been determined that to boil 2 kg of rice, given a gas supply consisting of approximately 58% methane, requires a burner with at least 12 - 15MJ/h capacity. [1].

Having selected the heat rating of the burner needed, flame related aspects of the burner must be established. Probably the two most important factors are *primary air entrainment* and *burning velocity*. First of all, the burning velocity was determined. According to Borman et al [2], burning velocity depends on the thermal diffusivity, average reaction rate, initial fuel concentration, flame temperature, ignition temperature and initial temperature of the reactants. Taking these calculations into considerations, it was calculated that the burning velocity should be approximately 0.22 m/s. Other texts suggest a burning velocity of between 0.25 m/s and 0.34 m/s [1, 2].

The amount of air entrained in this way depends upon a number of factors, including the pressure of the gas supply, size and shape of the injector orifice, mixing tube, airports and burner ports, as well as the specific gravity of the biogas [2]. The optimum air to fuel ratio is 5.5:1, which implies that 5.5 parts of air must be entrained for every part of fuel [2]. Knowing this figure the injector orifice and throat area can be altered to control this ratio $R$, such that

$$R = \sqrt{S\left[\left(D_t / D_o\right) - 1\right]} \qquad \text{(Eq. 6.1)}$$

This equation is valid for a flame port area, $A_p$ between 1.5 and 2.2 times the throat area, where $R$ is the air-to-fuel ratio, $D_t$ is the throat diameter, $D_o$ is the orifice diameter, and $S$ is the specific gravity of the gas.

Calculations can and have been performed using this formula to define appropriate orifice and throat areas, although testing must be completed to confirm their performance. Also the mixing tube between the throat and the flame ports must be long enough to allow the gas and air to mix thoroughly. Thus, as the gas reaches to the flame ports, secondary aeration occurs, as air is drawn out of the surrounding air and combusted also. Testing must be performed on different designs of burner to define which combination of the parameters mentioned above is the most efficient.

## 7. TESTING

In order to determine which burner system is the most efficient over the required range of biogas compositions (40 – 60% methane) a number of test scenarios must be performed. Figure 2 illustrates schematically the set-up that is typical of the testing process. Nitrogen ($N_2$) is added to a supply of natural gas to simulate the various compositions of biogas, as the nitrogen has no heating value, and therefore acts in the place of carbon dioxide ($CO_2$). Both the nitrogen and natural gas flow through separate flow meters so that composition can be determined before the two gases mix at the Y-junction as illustrated. The simulated biogas then flows through the nozzle of the inlet, drawing primary air into the burner with it, before igniting at the burner ports.

Flame stability is determined by simply observing the flame under a range of different conditions (i.e. flow rate, inlet size). Recording the time to boil 1 litre of water, and comparing it with the gas consumed and calorific rating provides an estimate of burner efficiency. The results are then tabulated and graphed where possible, to provide a visual interpretation of the data.

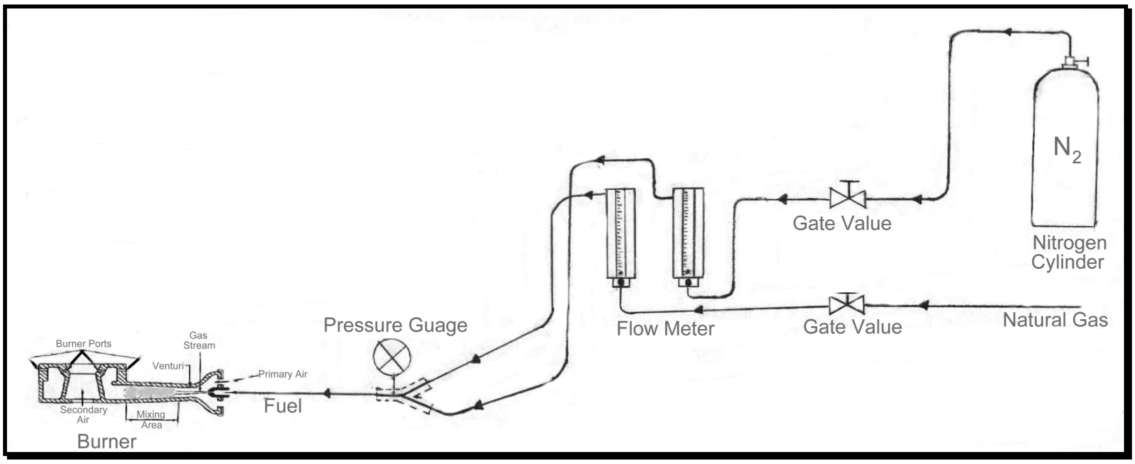


**Figure 2** – Systematic diagram of testing arrangements

## 8. CONCLUSIONS & FURTHER WORK

At the conclusion of this project, we plan to produce a design for an efficient, simple and inexpensive burner system. The need for a biogas as a means for cooking is increasing amongst developing countries. By completing this project, we aim to simultaneously help people in Philippines and to produce an efficient combustion system using biogas. In this project we will only be looking at the single gas burner system for basic domestic cooking in the home used in the Samar village in Philippines (if time permits we will be also looking for the research into the addition of a gas water heater or oven). Periods of testing still remain in order to determine the overall efficiency and performance of the designed burner system over a range over different methane concentrations.

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