# FEASIBILITY ANALYSIS OF HYBRID SOLAR CONCENTRATOR AND BIOGAS POWERED PROTOTYPE STEAM ENGINE

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*Abstract*— **This study presents a prototype design of hybrid solar/biogas fed steam engine mechanism to overcome the dependency on the contemporary sources of energy. This allows the two alternative sources to supply the load separately or simultaneously depending on its availability.Bio gas is a hopeful source, which, if used to its potential can be help in various factors like, employment generation and reduce impacts of global warming. Similarly, solar is another source which, if tapped to its potential can be beneficial in various ways. In this work, Biogas has been produced by a method where the mixture of water chestnut, water hyacinth and cow dung are put in the ratio of 1:1:2. The three variants were charged into a 20L portable bio-digester in the ratio of 1:1 with water. They were subjected to anaerobic digestion under a 35 day retention period and mesophilic temperature range of 26$^o$C-35$^o$ C. A silver coated dish collector of 1.545 m$^2$ is used as solar concentrator. Energy obtained from both the sources is used to produce low temperature steam to run a prototype steam engine. The temperature and biogas yield was measured and the energy output from the hybrid steam engine prototype was calculated.**

*Index Terms*— Hybrid energy system; solar concentrator; Bio gas; steam engine; Bio digester.

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## I. INTRODUCTION

Biomass materials are used since millennia for meeting myriad human needs including energy. Main sources of biomass energy are trees, crops and animal waste. Until the middle of 19th century, biomass dominated the global energy supply with a seventy percent share [1].

The potential for biomass boilers in India is vast with over 370 million tons of biomass being produced every year. Biomass is available from agricultural wastes, direct harvesting and as a by-product from industries such as rice mills, sugar mills and saw mills. However, due to problems with infrastructure and the seasonal variability of biomass in India, consumers are struggling to obtain a consistent fuel supply. Furthermore, while biomass is still competitive, prices have increased considerably in recent years. [2]

Today, biomass accounts for approximately 12% of world energy consumption. Yet the potential of using biogas has so far been unexploited, especially in the form of livestock manure in the agriculture system.

Hybrid power system has a great future due to its more flexibility in operation. Research and development efforts in solar, wind, and other renewable energy technologies are required to continue for, improving their performance, establishing techniques for accurately predicting their output and reliably integrating them with other conventional generating sources. Hybrid energy systems are best suited to reduce dependence on fossil fuel using available wind speed and solar radiations. These energy systems are considered as one of the cost effective solutions to meet energy requirements of remote areas. [3]

Biomass is biological material from living, or recently living organisms, most often referring to plants or plant-derived materials. As a renewable energy source, biomass can either be used directly, or indirectly—once or converted into another type of energy product such as biofuel. Biomass can be converted to energy in three ways: thermal conversion, chemical conversion, and biochemical conversion.



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Traditionally cow dung has been used as a fertilizer, though today dung is collected and used to produce biogas. This gas is rich in methane and is used in rural areas of India/Pakistan and elsewhere to provide a renewable and stable source of electricity.

Before the fresh animal manure is processed it is stored in a collector tank inside the homogenization tank which has a mixer to help homogenization of the waste stream. The waste is uniformly mixed then poured into anaerobic digesters where stabilization of organic waste materialize.

In anaerobic digestion, a series of bacteria converts organic material into methane and carbon dioxide. Most of the commercially operating digesters are plug flow and complete-mix reactors operating at mesophilic temperatures. This type of digester use varies with the consistency and solids content of the feedstock, with primary purpose and capital investment factor of the digestion.

A. Biogas contains a notable amount of hydrogen sulfide ($H_2S$) gas which needs to be tear off since it is highly corrosive in nature. The elimination of $H_2S$ takes place in a biological desulphurization unit in which a restricted quantity of air is added to biogas in the presence of specialized aerobic bacteria which oxidizes $H_2S$ into elemental sulfur. The use of Biogas can be for domestic cooking, industrial heating and combined heat and power (CHP) generation and sometimes even for vehicle fuel. The digested substrate can be subjected to solar drying and conditioning to contribute high-quality organic fertilizer to the farmers.

**1.1Water Hyacinth**

During the process of cutting down plant population, it can be used as a Some places in the world are currently using a method known as anaerobic digestion to process to extract methane gases from biomass. This method is currently being used with human waste in India, instead of water hyacinth. This practice not only justifies the disposal of the plant, since this is seriously infesting those regions in the form of anaerobic digestion, but also extracting the methane in the process and using it as fuel for communities .

It's been determined that the abundance of this plant on a year round basis leaves plenty of room for alternative fuel. One hectare of Water Hyacinth standing crop thus produces more than 70,000 m3 of biogas [4]. 1 kg of dry matter can yield 370 liters of biogas, giving a heating value of 22,000 kJ/$m^3$ (580 Btu/ft3) compared to pure methane (895 Btu/$ft^3$) (Curtis and Duke, 1982) [5]. Its habitat ranges from tropical desert to subtropical or warm temperate desert to rainforest zones. It tolerates annual precipitations of 8.2 dm to 27.0 dm (mean of 8 cases = 15.8 dm), annual temperatures from 21.1°C to 27.2°C (mean of 5 cases = 24.9°C), and its pH tolerance is estimated at 5.0 to 7.5. It does not tolerate water temperatures >34°C. Leaves are killed by frost and salt water, the latter trait being used to kill some of it by floating rafts of the cut weed to the sea. Water hyacinths do not grow when the average salinity is greater than 15% that of sea water. Inbrackish water, its leaves show epinasty and chlorosis, and eventually die [6].

**1.2 Solar Concentrator**

Solar concentrator is a device that allows the collection of sunlight from a large area and focusing it on a smaller receiver or exit [7].The device that is used in high temperature solar concentrators for the conversion of concentrated solar radiation to heat is called "receiver". It is designed to absorb the concentrated solar radiation and to transfer as much energy as possible to a heat transfer fluid. Losses originate from the fact, that the absorbing surface may not be completely black, that it emits thermal radiation to the environment, because it has an elevated temperature, and that convection as well as conduction occur.

The material used to fabricate the concentrator varies depending on the usage. For solar thermal, most of the concentrators are made from mirrors while for the BIPV system, the concentrator is either made of glass or transparent plastic. These materials are far cheaper than the PV material. The cost per unit area of a solar concentrator is therefore much cheaper than the cost per unit area of a PV material. By introducing this concentrator, not only the same amount of energy could be collected from the sun, the total cost of the solar cell could also be reduced [8].

The Rankine cycle is a thermodynamic cycle which converts heat into work. The heat is supplied externally to a closed loop, which usually uses water as the working fluid. This cycle generates about 80% of all electric power used throughout the world, including virtually all solar thermal, biomass, coal and nuclear power plants.

**1.3 Scope and objective of the work**

The objective of this study is to

1.To a develop a hybrid biomass/Solar powered steam engine prototype for demonstration

2.To study its feasibility for potential applications in rural areas

3.To quantify the energy output from the steam engine.

## 2. Experimental Methodology

**2.1 Material**

The various materials and design parameters used for developing a hybrid steam engine prototype are listed below

**Bio Digester**: A 20 liter plastic carbouy, Bio-mass (water hyacinth, cow dung, and water chestnut) was used as Biodigester (Fig .1)

**Solar Collector**: Silver Coated Dish Collector (radius= 35cm), Pressure Cooker Valve.



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Parameters**:** Collector Area 1.545 $m^2$, Receiver Diameter 14cm,Receiver Area 0.01539$m^2$,Concentration Ratio = Area of collector/Area of Receiver= 1.545/0.01539= 100

**Steam Engine**: Break Piston, Bicycle spoke. Flywheel, Cast iron cylinder (diameter=1.5 inch, height= 6 inch), Connecting rods cut from aluminum plate, Plywood stand

Parameters: Piston: Swept Length 4cm, Diameter 3.8cm, Volume of the Piston 45.34$cm^2$, Flywheel: Diameter 4.6 cm, Slide Valve

Accessories: T Valve, Mylar Balloon, Bunsen Burner, Rubber Cork & Pipes, Aluminum Container (1.3 Liters) , Epoxy glue

Fig.1: Biogas Setup

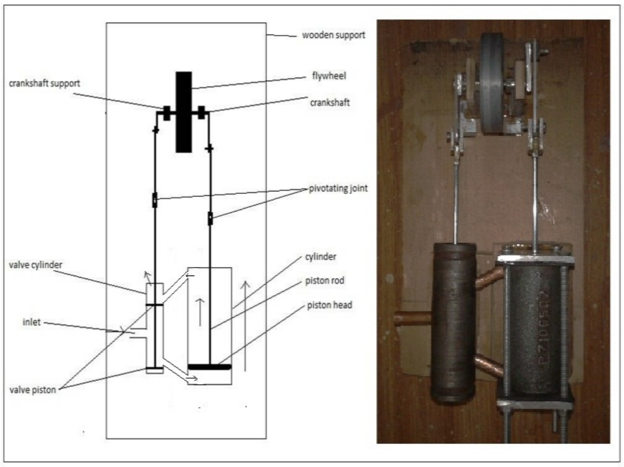


Fig.2: Double-acting Piston and Steam Engine Setup

The double-acting piston was an important improvement for the steam engine. The steam piston for this engine reciprocates slowly compared to other arrangement. The double-acting engine described here operated smoothly and identically in both directions (Fig .2).

**2.2 Digester Design**

The bio-digester composes a 20L water can with the neck closed with a cork as shown in Fig.1. The neck was made air-tight to prevent any escape of biogas with the help of a araldite .The cork was drilled and a plastic T valve was inserted. The first outlet was connected to a spherical mylar balloon with the second being connected to the Bunsen burner. After the biogas was produced it was stored in mylar balloon. The bio-digester was then kept in the bio-energy lab where the ambient conditions were maintained throughout the day. In order to check the flammability of the gas a bunsen burner was used.

**2.3 Preparation and Feeding of Biomass**

Water hyacinth (Jal Kumbhi) and Water Chestnut (Singada) was obtained from the lakes of Bhopal. Prior to usage, the water hyacinth and water chestnut were chopped and dried. Cow dung was obtained from a nearby village in MANIT. 500 gms of both aquatic weeds were kept to dry. Once the weeds are dried they are chopped .The chopped aquatic plants were then mixed with fresh cow dung, in the ratio of 1:2 by volume. The bio-digester was fed in this blend along with water in the ratio of 1:1 by volume, making total volume as 18L. The digester contents were then stirred adequately and on a daily basis to ensure homogenous dispersion of the constituents of the mixture.

**2.4 Factors**

The main factors that affect the production of biogas from livestock are pH and the temperature of feedstock. It is well known that a biogas plant works optimally at neutral pH level and mesophilic temperature of around 35$^o$ C. The ratio of Carbon-nitrogen in the feed material is also an important factor and must be in the compass of 20:1 to 30:1. Animal manure is evaluated ideal for extreme gas production as it has a carbon- nitrogen ratio of 25:1. Concentration of Solid in the feed material is also very important to verify sufficient gas production, as well as easy blending and handling. Hydraulic retention time (HRT) is the factor that is most important in determining the volume of the digester as a result of which determines the cost of the plant; the longer the retention period, the higher the construction cost. The amounts of sunlight and concentration ratio of the solar concentrator are also essential factors influencing the process.

Fig 3: Hybrid Biogas Powered Steam Engine Setup



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**2.5 Analysis**

Table 1: Water Heating potential from Hybrid Solar Concentrator/Biogas System

| S. No. | Time (Hrs) | Solar Intensity $W/m^2$ | Ambient Temperature($^oC$) | Temperature of container ($^oC$) (without biogas combustion) | Temperature of container ($^oC$) (with biogas combustion) | Temperature of water($^oC$) | Flow rate of Biogas ($m^3/s$) |
|---|---|---|---|---|---|---|---|
| 1. | 10:30 | 720 | 36 | 65 | 75 | 70.1 | 0.031 |
| 2. | 11:00 | 788 | 37.7 | 70.5 | 82 | 77 | 0.031 |
| 3. | 11:30 | 845 | 39.3 | 77.6 | 87.6 | 81.7 | 0.031 |
| 4, | 12:00 | 955 | 40.8 | 83.2 | 95.2 | 88 | 0.025 |
| 5. | 12:30 | 985 | 41 | 93.1 | 103.1 | 99.9 | 0.025 |
| 6. | 13:00 | 970 | 41.5 | 95 | 105 | 100 | 0.025 |
| 7. | 13:30 | 933 | 41.8 | 96 | 108 | 102 | 0.021 |
| 8. | 14:00 | 840 | 42 | 103.6 | 112.5 | 105.7 | 0.021 |
| 9. | 14:30 | 781 | 42.4 | 105.9 | 115 | 111 | 0.021 |
| 10. | 15:00 | 645 | 41.6 | 84.7 | 95 | 93 | 0.021 |
| 11. | 15:30 | 580 | 41 | 78.3 | 85.4 | 82 | 0.020 |

Gas production was measured in $dm^3$ per kg of slurry (15kg) by obtaining the diameter of mylar balloon using a measuring tape. Flammability was checked by igniting the gas at Bunsen burner. In order to get a better and assured result from the experiment, hybrid biogas powered steam engine was tested in the outdoor environment (Fig .3). Steam production from the system has been determined by adding the energy input from both the biogas and the solar concentrator.

## 3. Results and Discussion

**3.1 Production of Biogas**: The experiment was carried out under ambient temperature range of 26 to 36$^o$C and within a retention period of 35 days. The digester commenced biogas production within 24hr of its charging. The output gas obtained became flammable within 24hr of charging the digester. The gas production and its flammability reduced drastically on the 17th day and increased after 22nd day. When the biogas production resumed, it was observed that the production was quite high and continued long until the blend nearly stopped production. The cumulative biogas yield of the digester was lower in the first 17 days. A highest of 1.21L of biogas was produced on the 19th day. Overall 11.41L of biogas was accumulated by the end of the retention period. The average per day production of biogas was 0.326L/day. The general accepted mean calorific value of biogas is 20MJ/$m^3$. The energy that can be obtained from 11.41L of biogas would be 228KJ.

**3.2 Production of Steam**: Once the gas production reached its maximum limit, biogas digester was integrated to a solar concentrator .The output of the biogas is used to heat the aluminum container. Additional input energy is provided by the solar concentrator to the container. The water temperature and container temperatures increased continuously as long as the energy from both the sources is available Water temperature increased to 111° C from initial temperature of 28° C during the process. The experimental results are presented in Table 1.

Specific Heat Capacity of Water: 4.186 kJ/kg °C

Calorific Value of Biogas : 19 to 25 MJ/$m^3$

Density of Biogas: 0.75kg/$m^3$

**3.2 Running of Steam Engine:** The steam produced from the Hybrid solar concentrator/biogas system was used to run a double acting reciprocating steam engine prototype. The engine continuously ran as long as the steam was supplied .Thus it is successfully demonstrated that the solar concentrator/biogas powered steam engine is technically feasible. However, further Research is needed in this area to develop a feasible design for practical application.

## Conclusion

This work is an attempt to utilize biomass energy and solar thermal energy to produce mechanical work. The mechanical energy produced can be used to run the steam engine. Furthermore, this project finds its application most prominently in rural areas, especially of central and southern India because of abundant presence of biomass and prolonged presence of solar radiation throughout the day. Further research work in this area may lead to higher efficiency and development of economically viable alternative source of energy. Lot of research can be carried out in the area of integration of solar energy with biomass energy sources and this concept can lay the very foundation for the work in this field.

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