SMALL POWER ENGINE FUELED WITH BIOGAS

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Abstract

The paper presents a biogas supplying system for small power engines which are frequently used in rural regions. The system is composed of a simple biogas filter and a biogas/gasoline conversion kit.

Biogas filter consists of two components: H_2S treatment component by iron oxide and CO_2 absorption component by water. Thanks to the filter, the richness of biogas increases up to 30% and H_2S concentration decreases to 0.5% of its original value. "Clean biogas" after filter can be used for fueling internal combustion engines.

A biogas/gasoline conversion kit is developed on the base of GA5 LPG/gasoline conversion kit used on motorcycles. A supplementary regulator is needed when using stationary engine.

The biogas supplying system is tested on two stationary spark ignition engines of 2HP and 4HP. The results show that the emission of engines fueled with biogas is reduced from 50 to 90% in comparison with using gasoline. Fuel consumption is about 0.85 m^3biogas/kWh.

Keywords: Biogas, Gas engines, Biogas-gasoline conversion kit

1. Introduction

Biogas is today more and more popular in rural regions of Vietnam. It contributes to resolve two problems related to environment protection and energy in the regions where more than 80% Vietnamese population live. Biogas is actually often used for cooking. But farmers need also energy for their production, particularly in family scale. Thus small power internal combustion engines fueled with biogas for producing electricity, pumping, milling... are very useful to improve quality of life and production in these areas.

According to a survey, in the provinces of Quangnam, Quangngai, Quangtri and Danang city (central region of Vietnam) there are about 500 biogas digester producing about 250,000 cubic meters of biogas per year. Most of biogas producing digester are in family-size farms with the capacity of from 7 to 14 m^3. Few larger ones (up to 40 m^3 volume) have been found in community biogas plants. So far, there are more than 300 biogas digester in Danang city. These biogas digester not only supply people clean cooking fuel but also serve as a way of treating wastes from production and breeding farms, a solution to environment protection and natural resources preservation.

Direct combustion is the simplest method of biogas energy utilization. The growing demand for household energy further pushes up the development of biogas utilization in producing power for working machines such as pumps, mills, regrigerators... The use of biogas to generate electricity is worth of considering, particularly because biogas is practically considered as an ideal fuel to run engines to generate electricity. Utilization of biogas for fuel small power internal combustion engines is an important contribution to improving living conditions of people in rural regions of Vietnam.

Biogas cleaned-up by treatment systems is necessary for fueling internal combustion engines. Such biogas may be withdrawn from large-size treatment systems like landfills. Unfortunately, the stationary biogas fueled engines available in our markets are mostly large-power series and much more expensive than the same power ones that are fueled with the traditional fuels [2].

A Venturi mixer is used to provide air-biogas mixture for the above-mentioned type of engines. In most cases, it is designed for biogas and natural gas having heating value more than 37,000 kJ/m^3 and the fuel pressure intaking to mixer is within 40-50mbar. Such requirements actually are not suitable for small-scale biogas production in rural areas of Vietnam. Therefore, study on designing an appropriate system fueling biogas to small-power engines (under 5kW) is an urgent task of dealing with the energy shortage in rural areas.

Biogas consists mainly of methane (50-70%) and carbon dioxide (25-50%), with smaller amount of water vapor and trace amount of hydrogen sulfide (0-3%), hydrogen (0-1%) and other impurities. Hydrogen sulfide typically is the most problematic contaminant because it is toxic and corrosive to most equipment. Being fired in engine, H_2S corrodes the parts of intake-exhaust pipe shortening engine life. Additionally, combustion of H_2S leads to sulfur dioxide emission, which is harmful to environment. Carbon dioxide is considered as one of non-combustible gases and it may cause reduction of biogas energy content due to its various dilution. Water vapor in biogas has the same effect as carbon dioxide.

In the previous studies, we have successfully refined biogas to fuel the pilot motorcycles [5], [6]. In this paper, the design of a mature system for feeding biogas to the small-power stationary engine driving a generator is presented. The system consists of a biogas clean-up instrument, a fuel-air mixer kit and an extra electronic speed control unit.

2. Biogas clean-up instrument

2.1. H_2S removal process:

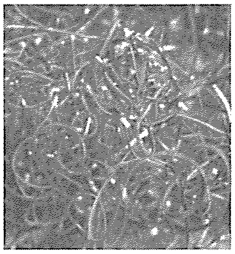
In the study, we use simple method, iron oxides to remove sulfur by forming insoluble iron sulfides [1], [4]. Iron shavings are the most well-known as the subtance that is harmless to groundwater and allowed to dicharge into landfills (EPA) [3]. Iron shavings are pre-treated by oxygenation to form the coated iron oxides layer. This process occurs naturally in air or by setting them on fire. The chemical reactions involved are shown in the equations:

$$Fe + 1/2\ O_2 \rightarrow FeO$$

$$2Fe + 3/2O_2 \rightarrow Fe_2O_3$$

$$3Fe + 2O_2 \rightarrow Fe_3O_4$$

The formed iron oxides are the mixtrure of FeO, Fe_2O_3, Fe_3O_4. The above chemical reactions can be accelerated by watering during combustion. The oxidized process achieves when the colour of iron shavings surface becomes yellow chrome or scarlet (Figure 1).



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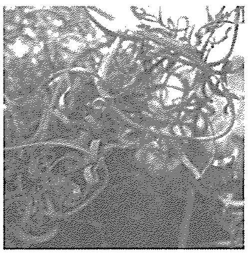


b

Figure 1. Iron shavings before (a) and after (b) being oxidized

Going through the iron oxides media, H_2S is removed from biogas via reactions:

$$Fe_2O_3 + 3H_2S \rightarrow Fe_2S_3 + 3H_2O$$

$$Fe_3O_4 + 4H_2S \rightarrow FeS + Fe_2S_3 + 4H_2O$$

$$FeO + H_2S \rightarrow FeS + H_2O$$

It is possible to extend bed life by admitting air, thereby forming elemental sulfur and regenerating the iron oxide, but eventually the media becomes clogged with elemental sulfur and must be replaced. After the first week of operation (average 4hours per day), removal efficiency reaches 99,4%. After a month, it reduces to 98%. Spent iron shavings can be regenerated in place by recirculation of the gas in the vessel. Alternatively, this can be accomplished by removing the iron shavings and exposing it to air by spreading it out in thin layers and periodically turning it. However, regeneration practically is only once or twice before new iron shavings are needed. Predominant reactions are shown in Equations

$$Fe_2S_3 + O_2 \rightarrow Fe_2O_3 + 3S$$

$$FeS + O_2 \rightarrow FeO + S$$

Equations represents the highly exothermic regeneration of iron oxide and formation of elemental sulfur at normal temperature. To accelerate spent iron shavings can be fired for 15 minutes. However, the regeneration stage forms polluted dioxide sulfide SO_2 upon exposure to air:

$$Fe_2S_3 + 9/2O_2 \rightarrow Fe_2O_3 + 3SO_2$$

$$FeS + 3/2O_2 \rightarrow FeO + SO_2$$

Table 1. H_2S Removal Efficiency

	For 1 hour operation		For 20 hours	
	Raw gas	Treated	Raw	Treated
H_2S concentration (mg/l)	0.17	0.0005	0.20	0.001
ppm volume	112	0.33	132	0.66

Regeneration practically is only twice or three times before new iron shavings are needed. Fired iron shavings are impregnated with wood shavings and shawdust in the ratio 1:1 and then feeds into an adsorption vessel (Figure2). With the diameter of 0.2m and 1.5m in height, the PVC vessel is capable of containing a mass of 8 kg media material and processing 0,86 m^3 biogass per hour. Average pressure loss across the H_2Sremoval column is about 0.3 mbar during operation.

The instrument has installed at Social Sponsoring Centre in Dason, Hoavang district, Danang city. Based on analysed results shown in Table 1 we can see that the H_2S removal effieciency of the instrument is very high (above 90%)

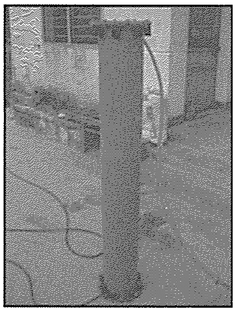


Figure 2. Removal H_2S column

Figure 4. Overview of CO_2 scrubber setting in Dason Centre for Social Sponsor

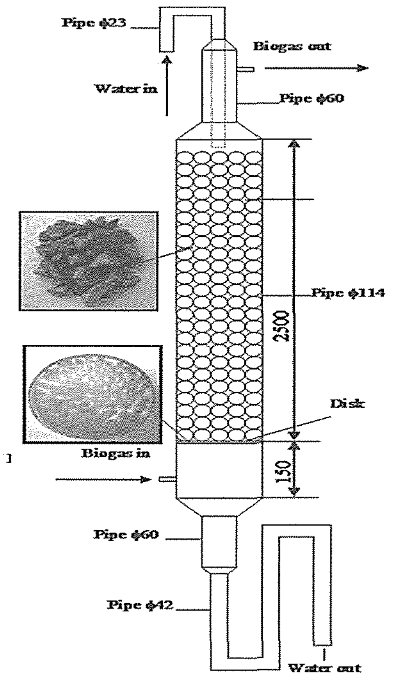


Figure 3. Removal CO_2 scrubber

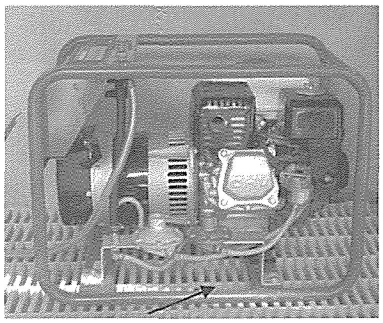
2.2. CO_2 scrubber

Liquids with increased solubility for CO_2 are typically chosen over water, but the principal advantages of water as an absorbent are its availability and low cost. Absorption of acid gas produces mildly corrosive solutions that can be harmful to equipment if not controlled. CO_2 and water contrariwise contact with each other in a scrubber. Water goes downward and absorbs CO_2 in biogas when biogas goes upward of the scrubber. A neutral material layer consisting of brickbats, woodchips and stones as absorbed media is fitted into the scrubber by a perforated mica sheet to intensify the gas-water contact. Figure 3 describes the selected size of our scrubber. The scrubber operates at biogas flow rate of 0.86 m^3/h, CO_2 concentration of inlet is 36.47%, and 19.22% in outlet biogas stream. CO_2 removal efficiency reaches 47.30%. Pressure drop across the bed about 5mbar.

3. System of feeding biogas to small-power engine

After filtration, biogas now meets the requirement as a fuel for internal combustion engines. In our work, a system of feeding biogas into small spark ignition engines driving generator has designed. The system has to meet the basical requirements of maintaining invariant frequent (50Hz) of electric current output in any loading regime. In principle, the LPG/gasoline GA5 kit can be used for this purpose in case load varies inconsiderably [7], [8]. Experiments in biogas 4HP engine-generator group fitting GA5 kit made a good exhibition in fixed loading mode [9]. When engine load suddenly increases (e.g. starting water pump...), engine power heavily depresses and then is turned off automatically. It can be understood that when load suddenly increases, engine speed reduces at once. Although the engine initial governor replies to open the butterfly valve, but it fails to create the necessary pressure drop for sufficient suction of fuel gas. As a result the engine unavoidably breaks-down due to poor mixture.

For the purpose of improving the above-mentioned fuel system, an extra electronic speed control unit is mounted to the GA5 kit. Principle scheme of mixing system for biogas engine-generator combination is illustrated in Figure 6. The system consists of the power valve 1 with its main injector nozzle 3 fixed in the "bottleneck" of the Venturi mixer; the idling valve with its idling gicleur 10 connecting to the bores 6 at the back of butterfly valve; the solenoid valve 12 with the gicleur 9 in parallel to the 11, 13 group. The solenoid valve-controlled electronic circuit 14 is supplied a 12V AC power from generator via plugs 15. Modification doesn't change the initial engine fuel system that includes carburetor 7, fuel switch 8, gas butterfly valve 5 controlled by a governor via shaft 4. Operation principle is described in brief as follows:



GA5 kit

Figure 5. Biogas engine-generator combination 4HP with GA5 kit [9]

- When using gasoline as fuel, engine normally operates in initial mode with gasoline switch in the "open" position, biogas switch in the "close" one.
- When fueled with biogas, on the contrary, gasoline switch is in the "close" position, biogas switch is in the "open" one. Filtered biogas is fed into system through pipe 16.
- When engine still in starting mode, solenoid valve 12 in the "close" position, suction pressure ("vacuum") in space behind the diaphragm will open the idling valve resulted in a minimum amount of biogas passes on to the engine chamber via the idling gicleur 10 maintaining a stable operation of engine in idling mode.

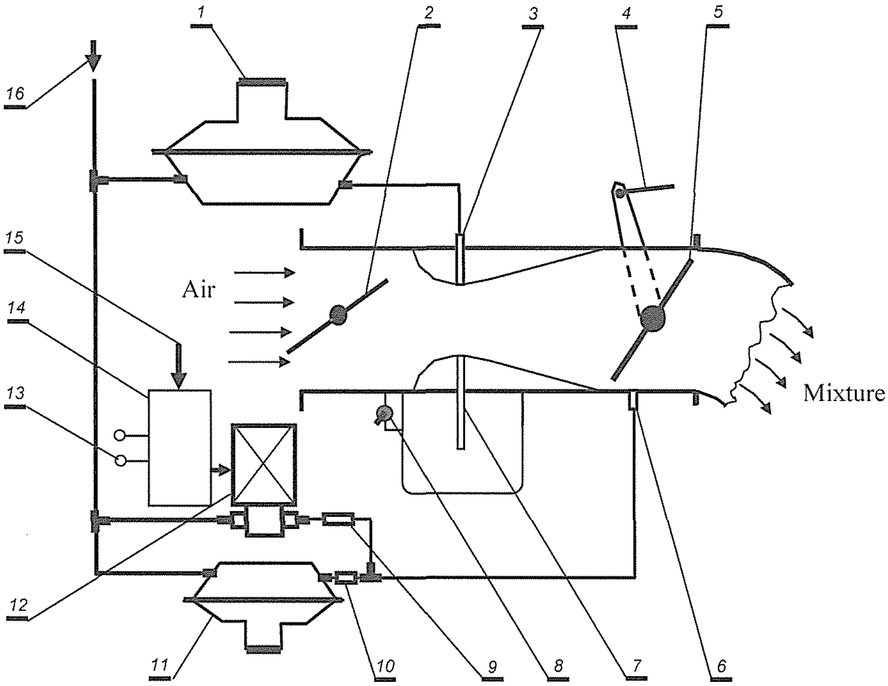


Figure 6. Principle schema of mixer system of the biogas engine-generator combination

- When load gradually increases, simultaneously, thanks to the shaft 4, the governor acts to open slowly gas butterfly throttle 5, so the air is sucked into the engine intake via the butterfly throttle raises. The more the throttle 1 is opened for more power, the more the vacuum from the engine intake becomes effective in the "bottleneck" of Venturi mixer space and hence the more air and gas are allowed in through their increased openings.

- With suddenly increased engine load the engine speed becomes immediately slowdown resulted in suction pressure in the "bottleneck" of Venturi mixer space is dropped so small to open the throttle 1 for biogas input. And eventually, engine power heavily depresses and then engine is turned off automatically. To tackle the situation an extra electronic speed control unit including the solenoid valve 12, the electronic circuit 14 and the gicleur 9 is used for adding a suitable amount of biogas into engine in order to compensate the sudden increase of power demand. The unit operation principle is described as follows: with the suddenly increase in drag torque the generator output voltage drops down below 200volts. The voltage signals will be transmitted to the electronic circuit 14. The valve 12 can be operated by a solenoid mechanism which receives its impulse from the electronic circuit 14 which again has a sensor for the generator speed (or generator output voltage). In this case, valve solenoid 12 adds a suitable amount of gas passing through the valve cone 9 to tolerate the speed fluctuations. When generator output voltage increases to 200volts,

Figure 7. Experiment on Biogas engine-generator combination with extra electronic speed control unit

solenoid valve 12 simply closes and the engine operates in normal mode which engine speed is controlled by the main governor. Operating voltage of the extra electronic speed control unit can be adjusted by the rheostat in the electronic circuit 14.

Figure 7 shows the picture of 2HP biogas engine-generator group with extra electronic speed control unit in experiment [10]. Maximum and nominal output power of the engine-generator combination is 1.5 kW and 0.8kW. In the experiment, generator load consists of 10 bulbs with 100W power for each (figure 8). The experiment was carried out in two cases: In the first case: a slow increase in load was made by turning on the bulbs one by one. The experimental results showed that the engine still operated normally even if without the extra electronic speed control unit. In the other case, a sudden increase in load was made by turning on 5 bulbs once for each. The result showed that without the extra electronic speed control unit the engine would be broken-down automatically.

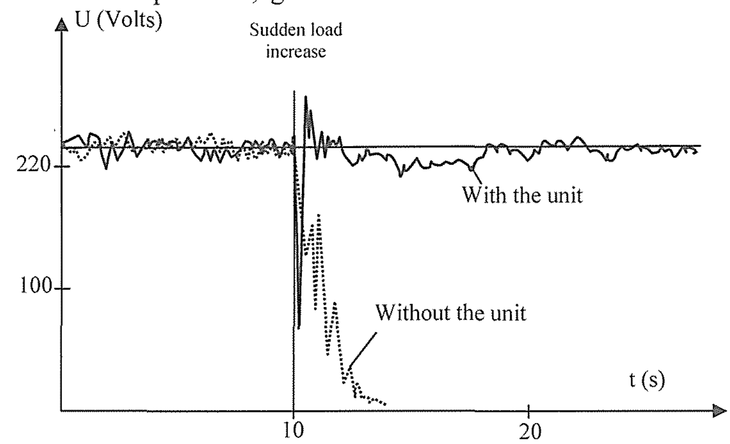


Figure 8. Generator voltage fluctuation in case with/without extra electronic speed control unit

4. The engine feature when fueled by biogas

Engine power evaluation was made by comparing the output capacity of the generator SH2000 driven by the engine Honda GX120 fueled with gasoline and biogas. Experiments showed an equivalence in the two cases.

Emission level of the engine was also compared in cases the engine fueled with gasoline and with biogas. The pollution measured results in the two cases are shown in Figure 9. Measurements were carried out in the variant load modes. Results showed a very small in pollutant concentrations in exhaust gas when engine runs by biogas (about 0,07% of CO and 30ppm of HC) in the critical rergimes making a great reduction of 78% for CO and 60% for HC in comparison with gasoline case.

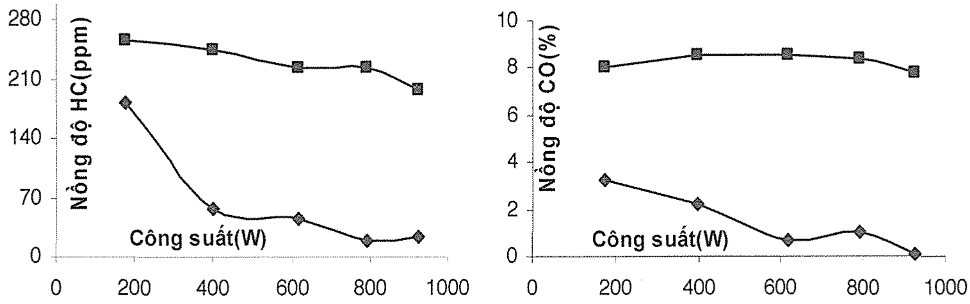


Figure 9. Comparison HC and CO concentration in exhaust gas of the GX2000 engine fueled by gasoline and by biogas

The engine economic feature was assessed by the fuel consumed rate in the different output powers of generator. Figure 10 illustrates the economic efficiency of generator GX200 using biogas as a fuel. Fuel-used efficiency is very high at the average load modes (consumed $1m^3$ biogas for 1.1kW). In the maximum output power the fuel-used efficiency reaches $0.94m^3$ biogas/kW.

At the present price of gasoline (11,800VND/liter), if the biogas engine operates for 8 hours per day, a user can save 800,000 to 1,000,000 VND per month.

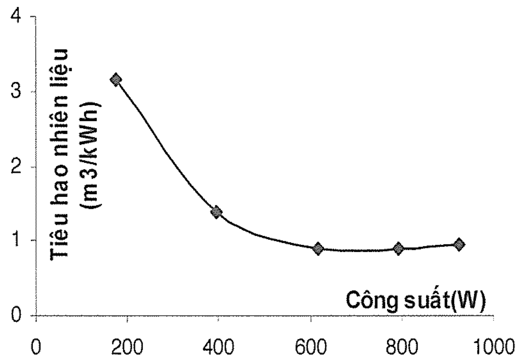


Figure 10. The economic efficiency of generator GX200 using biogas as a fuel

5. Conclussion

1. Various degrees of gas processing are necessary depending on the desired gas utilization process. As a fuel for Internal Combustion Engines, it is possible to use iron shavings for removing H_2S from biogas to protect downstream equipment (removal efficiency reaches 99%) and water for scrubbing CO_2 (efficiency: 50%). This oldest method still in practice is cheap and very appropriate to the conditions of Vietnam countryside.
2. To meet the requirement of operating stably in all load fluctuant modes, an extra electronic speed control unit is need to add to the primary LPG/gasoline GA5 kit originally using for motorbike.

Acknowledgement

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