Development of Biogas Compression System for Using in Household

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Abstract

This research presents the study and development of a biogas compression system for use in a household. A two horse power compression system was developed and the motor was used as a power source generator, including a gas scrubbing machine system. The result showed that the system could compress biogas into a 15 kg container, in the amount of 0.50 kg, operating time of 6.11 minutes, 1.35 kW of energy consumption or 0.138 kWh. Furthermore, increasing biogas by reducing the temperature before compressing was accomplished by three different methods; (1) air cooling system (2) water cooling system, and (3) ice cooling system. From the experiment, it was found that the (3) method could reduce to minimum temperature of 9.87 $^{\circ}C$ before compressing the biogas and gave 0.56 kg of final biogas (12% increase) by comparable energy consumption. From using biogas in a household as a substitute for LPG, it was found that use of a 15 kg-container of LPG was equal to the energy of 67 containers of biogas. This offers saving of 275.05 baht per one container of LPG. If a container of LPG could last for 7 days and the cost of compression system was 15,000 baht, the break even point would be 1.04 year.

Keywords: Biogas, Biogas compression system, LPG.

1 Introduction

At present, many countries, including Thailand are facing energy problems which result from an increase in energy consumption demand. Fossil fuel is the main energy resource which is non-renewable and also brings about global warming as a consequence. Therefore, countries worldwide are driven to seek a method to solve this problem. Alternative or substitute energy development is the option.

Thus, a policy promoting use of alternative sources of energy has been launched in Thailand, including biomass fuel, solar cell, wind energy, water energy, and especially, biogas. Biogas is considered to be a high potential alternative energy. It is produced in a large amount in Thailand and can be used as alternative in many sectors, such as, production from sewage water in industrial factories, animal droppings in a cattle farm, and fresh garbage from households, etc. Nevertheless, its potential has not been fully utilized. For example, a small swine farm generates more than enough biogas in a day, so the excess biogas is burned off in the environment, a consequence of waste which impacts the environment. From a preliminary survey, it was found that the emission of excessive biogas from a small swine farm could be utilized more efficiently.

There are 2 types of biogas utilization; (1) compression into a container, which is easy for using and for storage (2) use for electrical and heat generation, directly. The concept of this research aims to the compression of the excess biogas from a chicken farm into a container for use as an alternative energy in a household. The compression system is designed and developed for suitable use in a household. The expected results are a suitable method for biogas utilization and an original model of a biogas compression system for use as alternative energy. Moreover, the hope for a decrease in the expense of biogas producer, a decrease in the amount of energy imported from foreign countries, and to support the policy of alternative energy consumption which can eventually lead to domestic energy security.

2 Theory

2.1 Calculation of compression power

In this case, a biogas compressor was applied from an air-compressor. The power of compression ($\dot{W}$) can be calculated from the equation,

$$\dot{W} = \dot{m} C_p \left(T_2 - T_1\right) \tag{1}$$

Where,

$\dot{m}$ is mass flow rate ($kg \cdot s^{-1}$)

C_p is specific heat capacity ($kJ \cdot kg^{-1} \cdot {}^\circ K^{-1}$)

T_2 is temperature of biogas at the discharge (${}^\circ K$)

T_1 is temperature of biogas at the suction (${}^\circ K$)

2.2 Mass flow rate

Mass flow rate is calculated before calculation of compression power. The equation is

$$\dot{m} = f_c \frac{P_2}{RT_2}\left(V_2 - V_3\right) \tag{2}$$

Where f_c is frequency of compressor's rotation, which is calculated by $f_c = \frac{N}{60}$. In this case, the rotation was 1,500 rpm, thus

$$f_c = \frac{1,500}{60} = 25rpm .$$

P_2 is the pressure of biogas (bar).

R is constant value of gas ($kJ \cdot kg^{-1} \cdot {}^\circ K^{-1}$).

V_2 is cylinder volume when piston pump to P_2 point (cm^3).

V_3 is cylinder volume when piston pump is compressed to zero point (cm^3) (see Figure 1)

2.3 Biogas temperature after compression

The temperature of biogas after compression is increased and, the final temperature (T_2) could be calculated from;

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} \tag{3}$$

Where P_1 is the biogas's pressure before compression (bar), and n is a constant value, n=1.20.

2.4 Calculation of compressor capacity

Biogas compressor capacity (η_v) is calculated by the following equation;

$$\eta_v = 1 - CL\left[\left(\frac{P_2}{P_1}\right)^{\frac{1}{n}} - 1\right] \tag{4}$$

Where CL is the ratio of the reserved volume to the total volume of the cylinder.

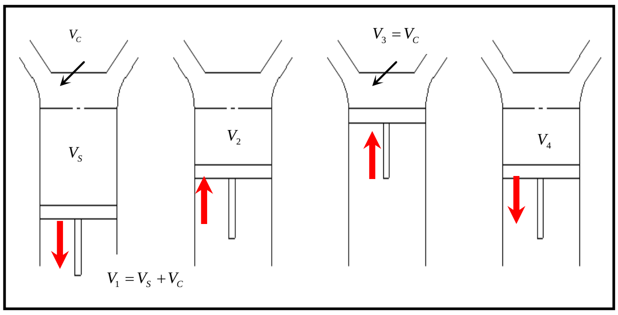

Figure 1 Operation of the piston

3 Biogas compression system developments

The biogas compression system is developed based on the principle of an air compressor design. The composition and properties of biogas are different than air, thus auxiliary equipment is added for a suitable system. The components could be separated into 3 parts, as follows;

Figure 2 Biogas compressor and motor

3.1 Biogas compressor

Calculation of power, defined T_1 = 303 $^{\circ}K$ and then calculated T_2 by equation (3). Using equation (2) to find $\dot{m}$, and give to equation (1), resulting in compression power being 0.958 horse power. The safety factor was fixed as 2, so the power from the calculation was 1.916 horse-power. According to the result, a two horse power piston compressor which modified from 2 horse power PUMA air compressor was selected for use in this research. The power source was a two horse power motor, 1 phase MITSUBISHI (Figure 2). The advantages of this piston compressor were durability and standard size for 15 bar of compression. The disadvantage was longer time-consumption when compared to other compressor.

3.2 Biogas upgrading equipments

Since the biogas was fermented from animal droppings, the composition was methane (60-80%), carbon dioxide (20-40%) and hydrogen sulfide (1%) by volume dependent on the source of biogas. When hydrogen sulfide combines with humidity in the air, sulfuric acid is produced which is dangerous to living organisms and acts as a corrosive agent which could erode house-wares [2]. Accordingly, hydrogen sulfide should be removed [3]. The removal protocol was scrubbing by sodium hydroxide solution (caustic soda) which rapidly reacts with the acid gas. The reaction is two phase as below

$$H_2S + 2NaOH \dashrightarrow Na_2S + H_2O$$

$$H_2S + Na_2S \dashrightarrow 2NaHS$$

Moreover, iron fiber was used as an oxidizing agent which produced ferrous/ferric sulfide precipitates in proper humidity conditions and with temperature more than 12 $^{\circ}C$ during which iron sulfide could be oxidized by air to be reusable iron oxide [4].

A biogas upgrading system was developed which ran the biogas through sodium hydroxide solution 2 times, then a run through iron fiber and then sent to decrease moisture by entrapment, and finally sent into the biogas compressor. Figure 3 shows the system using, 4 inch diameter and 80 centimeters long PVC tube and ¾ inch diameter copper tube which conducted the biogas into the sodium hydroxide solution.

3.3 Biogas cooling system

The initial temperature of the biogas before compressing was 30 $^{\circ}C$, and the final temperature would be increased to 172.84 $^{\circ}C$ after compression because of higher pressure. A cooling system was necessary for decreasing its temperature before compressing the biogas into a container. Figure 4 shows the cooling system next to a 150 watt electric fan, which blows air up to the biogas in the copper tube.

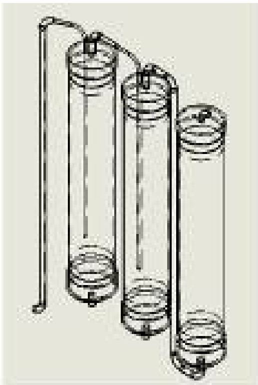

Figure 3 Biogas Scrubbing System

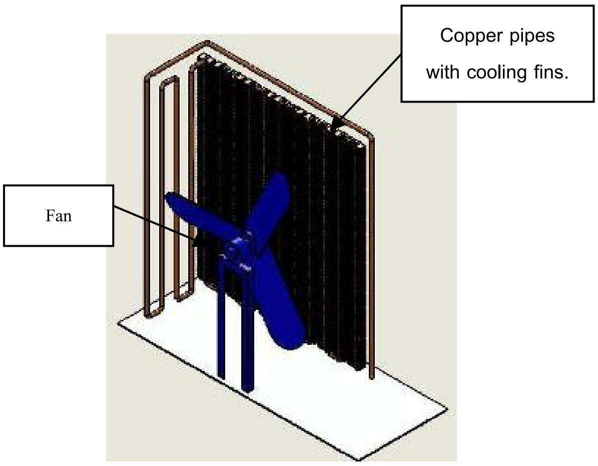

Figure 4 Biogas cooling System

Figure 5 Biogas Compression Systems

4 Materials and Method

4.1 Experimental tools

The experimental tools were comprised of clamp – on multimeter, digital weighing machine, stopwatch, 35 bar gas container, thermometer, and biogas compression system.

4.2 Heating value calculation method

The basic components of biogas were analyzed by GC-2014 which operated by technique of carrier gas to separate the simple components in suitable condition and analyzed by specific properties of substance, including calculation for type and quantity compared with a standard sample. The result showed that biogas consisted of methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2) and hydrogen sulfide (H_2S).

4.3 Analysis of biogas compression system capacity

The specified maximum pressure was 15 bat. The three conditions of the cooling system were (1) ice cooling system (2) water cooling system and (3) air cooling system. The target data were the amount of biogas, the compression time and the power of the electric machine. The process was to attach the container to the compressor; open the compression system, record the time, record the power of the motor, measure the pre and post temperature, respectively. The measurement was done at every 1 bar increase, from initial to 15 bar of internal container. Finally, close the container and measure the final weight.

Figure 6 GC-2014

5 Results

5.1 Heating value of Biogas

The heating value was 19.22 MJ/kg. The heating value was received from calculation and analysis of the gas components by using CG-2014 analytic machine. The components of biogas were methane (CH_4) 46.28%, carbon dioxide (CO_2) 31.13%, nitrogen (N_2) 22.59%, and hydrogen sulfide (H_2S) 0.0297%.

5.2 Biogas compression into container

The quantity of biogas which was compressed with 15 *bar* without using a cooling system was 0.50 kilogram. The researcher aimed to increase the quantity by decreasing the gas temperature before compressing into the container.

5.3 Biogas Upgrading

The use of biogas upgrading equipment could reduce the amount of hydrogen sulfide 15.63%, from 352 ppm to 297 ppm, which met the standard acceptable value for household use (less than 1,500 ppm) [5].

5.4 Biogas compression in each cooling system

The result showed that decreasing the temperature by a cooling system could increase the amount of compressed biogas in the container. The use of an ice cooling system could compress the maximum quantity of biogas at 0.56 kg. (See Figure 7 and Table 1). From consideration of the energy consumption, the result revealed that the maximum energy consumption was 0.146 kWh when using the ice cooling system. This was due to the temperature being the lowest after passing through the cooling system. (See Figure 8 and Table 1)

5.5 Using Biogas in Household as Substitute to LPG

The compression system could compress biogas into a 15 kg container and be used as a substitute to LPG in the household. The result showed that a 15 kg container had biogas 0.54 kg, giving energy about 10.38 MJ per 1 container, which could be used for 75 minutes for cooking. The cost of the compression method was calculated from unit of electricity comply to cost per unit (2.699 baht/unit), resulting in 0.369 baht. Compared to LPG, where a 15 kg container gives about 696 MJ of energy per 1 container, an costs 300 baht. According to the mentioned fact, using LPG 15 kg container (300 baht) was equal to 67 containers of biogas (15 kg container) which in total cost 24.72 baht and reduced the cost of LPG about 275.28 baht. If a container of LPG could be used for 7 days and the cost of the compression system was 15,000 baht, the break even point was 1.04 year.

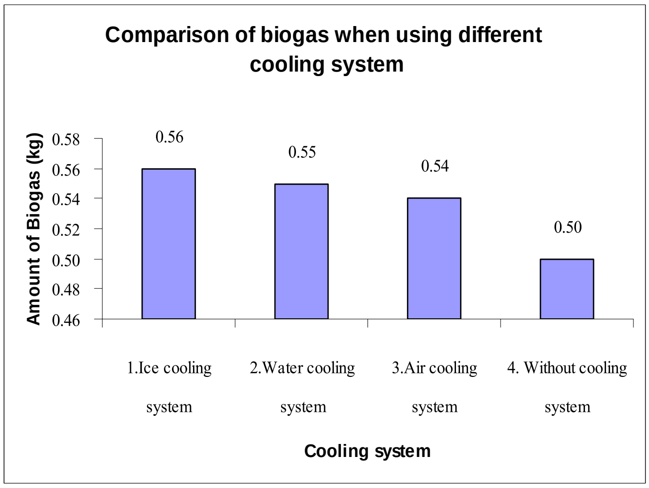

Figure 7 Comparison of biogas when using different cooling system

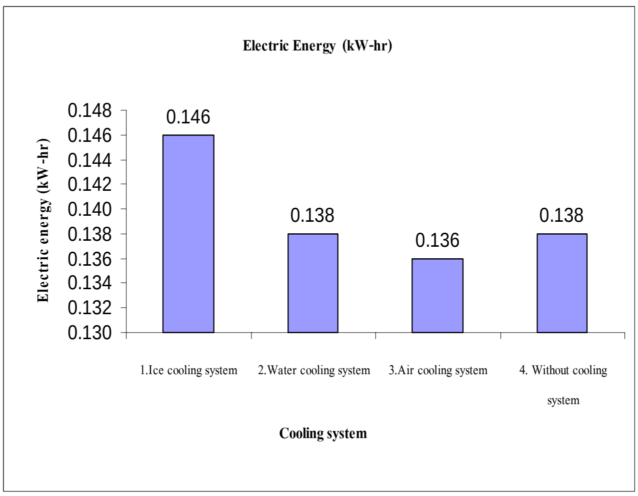

Figure 8 Comparison of electric energy consumption

Table 1 Summary of biogas compression into 15 kg container

Cooling system	Amount of biogas (kg)	Temperature (°C)				Time of compressing (min)	Electric Power (kW)
		T_1	T_2	T_3	T_4		
1.Ice cooling system	0.56	31.07	73.27	9.87	-4.27	6.03	1.45
2.Water cooling system	0.55	31.77	69.63	32.07	27.77	6.04	1.37
3.Air cooling system	0.54	31.43	64.03	30.07	28.77	6.16	1.33
4. Without cooling system	0.50	31.67	67.10	32.57	31.63	6.11	1.35

Annotation: T_1 Is temperature of biogas before compressing, T_2 Is temperature of biogas after compressing, T_3 Is temperature of biogas after passing through cooling system, T_4 Is temperature of cooling system.

6 Conclusions

This research was aimed at the study and development of the biogas compression system for use in a household. The biogas was compressed by a 2 horse-power motor, which adding with added cooling system and upgrading equipment. From the experiment it was found that the developed system could compress biogas into a 15 kg container with 15 bar of pressure, resulting in 0.50 kg of biogas. From the further study, increasing the biogas volume by decreasing the temperature before compressing, the result showed that the three cooling system methods could lower the temperature at 9.87, 32.07 and 30.07 °C, respectively. When the biogas was compressed by 15 bar, the quantitative outcomes of each cooling system were 0.56, 0.55, and 0.54 kg, respectively. The most effective method was the cooling system using ice, which increase the biogas 12% more than the conventional method (without cooling system).

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