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Commercial Stove Conversion to Biomethane in Thailand

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Abstract

This paper presents a study on converting a commercial stove from LPG to biomethane in Thailand. In this context the term ‘commercial stove’ is a single burner that is used by commercial street vendors in Thailand. They are sometimes referred to as fast stoves, outdoor stoves or single wok stoves. They differ from domestic stoves in that their power output can be up to 30kW which is 10 times greater. The fuel used in these burners is LPG, which in Thailand is a 70/30 mixture of propane and butane. In 2011 Thailand imported over 700,000 tones of LPG at a cost of almost $650 million. In addition to the cost, LPG is a non renewable fossil fuel that contributes to global warming. If a renewable fuel, such as biomethane produced from waste, was used instead this would lead to many economic and environmental benefits. In this paper biomethane will refer to an 85/15 mixture of methane and carbon dioxide produced from biogas. The biogas in this project comes from agricultural and industrial waste. The biogas undergoes a water scrubbing process to clean the impurities, such as hydrogen sulfide, and to increase the percentage of methane in the gas from around 60% to 85%. The final product, biomethane, can be used in automotive applications as an NGV fuel substitute. The purpose here is to investigate the possibility of using it as an LPG substitute in a commercial stove.

Unfortunately it is not possible to swap directly biomethane for LPG inside a commercial burner. Their Wobbe indexes are very different indicating non compatibility. This paper will describe the changes to the supply pressure and stove hardware that are needed to accommodate the conversion. An experimental setup to compare the flame size and structure for both fuels was built. The energy output from both sets of fuels was measured with a gas flow meter and confirmed with boiling tests. An infrared comparison was made between the flames from both fuels. Different hardware configurations were tested and an optimal design was selected. This design involved a maximum thermal output of 16kW instead of 13kW for LPG. As the heating time remained similar this resulted in a 12% less efficient burner design. The output from this paper is optimal conditions for conversion of commercial LPG stoves to biomethane.

***Keywords**:* Biogas, Biomethane, LPG conversion, Commercial Stove, Wobbe Index

1. Introduction

A commercial stove, such as that shown in Fig: 1 is widely used in Thailand, particularly among street vendors. It has a high heating rate, 30kW, which allows for fast cooking [1]. Sometimes they are known as single wok stoves, outdoor stoves, KB-5 or fast stoves. They mostly use LPG as a fuel source. LPG, a 70/30 mixture of propane and butane, is sold in portable tanks [2]. Thailand has gone from being a major exporter of LPG to importing 25% of its LPG requirements [3]. Slightly under half of all LPG used in Thailand is for cooking purposes [3]. The purpose of this paper is to investigate using biomethane as a fuel substitute for LPG in these commercial stoves. The advantages of using biomethane include, replacing a fossil fuel with a renewable source, less greenhouse gas emissions, smaller fuel bill for Thailand, more income for Thai farmers and producers of biomethane. Directly substituting the fuel is not possible because the difference in Wobbe Indexes, leads to an unstable flame on the stove head. The fuel pressure and the injection nozzle also need to be changed in order to burn biomethane. This paper will discuss the details of this conversion.

Fig. 1 Thai Commercial Stove

Biogas is a gas that contains about 40 – 70% Methane, Hohlfeld [4]. The other gases are Carbon Dioxide (15 – 30%), Hydrogen and Hydrogen Sulfide. Previous research has been done before on biomethane production and potential in Thailand. A nice summary is provided by Aggarangsi et al. [5]. In order to combust biogas effectively the impurities must be removed and the percentage of Methane increased. Water, dust and Hydrogen Sulfide can corrode compressors and piping systems. And Carbon Dioxide does not provide any calorific value. In this paper the method used to purify the biogas was the water absorption column. Details of how this works is provided by Ryckebosch [6] and Koonaphapdeelert [7]. Once the impurities have been cleared and the percentage of Methane is above 85% we refer to this gas as Biomethane.

Thailand gets about 80% of its primary energy from fossil fuels. One of the strategic aims of the ministry of Energy is to increase the use of renewables to 20.3% of the total energy supply by 2022, Chaiprasert [8]. The Energy Policy and Planning Office of Thailand hopes to save 1 million kilograms of LPG per annum through its livestock farm project, Wonsapai et al. [9]. However a direct way to utilize biogas potential in a commercial stove has not yet been studied. LPG that is regularly used is a mixture of 70% Propane and 30% Butane. The Wobbe index for this LPG is 85MJ/m^3, while that of 85% Biomethane is only 36MJ/m^3. The Biomethane therefore cannot be directly substituted for LPG. There needs to be some modification to the physical stove hardware and flow parameters in order to utilize Biomethane gas.

2. Experimental Setup

This experiment was setup in order to investigate how to burn biogas effectively in a commercial burner. The heating head, air inlet and injector nozzle are all shown in Fig. 2.

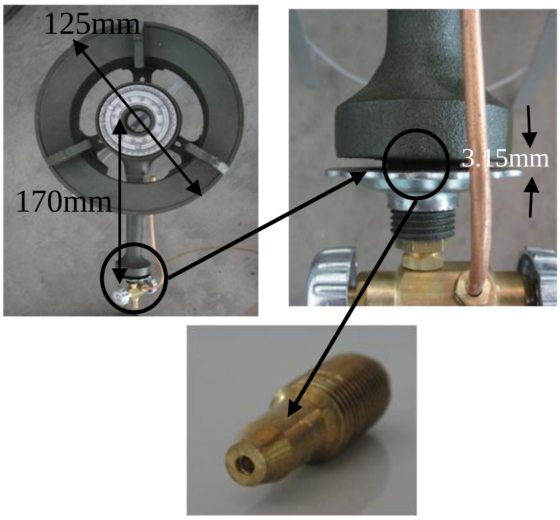

Fig. 2 Heating Head, Air Intake and Nozzle

LPG flows through the nozzle at gauge pressures with the range of 0.4 – 1.25 bar. This nozzle diameter is 0.7mm which causes the jet to entrain air. The gas air mixture then flows and mixes through the 20cm intake pipe before making a 90˚ turn and entering the burner head. A valve just before the nozzle controls the fuel flow rate. The air intake can be adjusted by varying the gap or area that the air flows through. Normally this gap is rarely adjusted and left at its default setting of 3mm. Since the Biomethane density is one half to one third that of the LPG it means that to get the same volume flow rate through the nozzle the jet velocity will be higher. This entrains more air than needed and results in high velocities at the heating head. This result causes flame lift off and is an unstable burning condition.

In order to slow down the jet velocity, two strategies are possible. The first one is to lower the fuel supply pressure. However this causes insufficient fuel to reach the heating head, causing a low flame and lengthy heating times. The second option is to physically increase the nozzle diameter, reducing the jet velocity and giving a more stable flame. This option was selected for these experiments.

The experiments consisted of changing the nozzle diameter, changing the Biomethane supply pressure and observing when there was a stable flame. This is a little subjective as a stable flame is not clearly defined. In this study a stable flame was one clearly anchored to the heating head, showing no signs of instability nor possessing any 'yellow tips'. Yellow tips indicate incomplete combustion due to insufficient oxygen. A map was generated over the area where a stable flame was generated. The next step was to measure the fuel flow rate at the stable points on the map and compare the heat output to that of a stove using LPG. The flow rates were measured using an Azbil CMG150N gas flow mater as shown in Fig. 3.

Fig. 3 Gas Flow meter

At two of the optimal settings efficiency tests were performed. These are tests based on the standard DIN EN 203-2. They involve heating 41.2kg of water and measuring the time required to do so. The efficiency is calculated from

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$$\eta = \frac{m_{water} . C_{water} . \Delta T}{Q_{fuel} . HV} \quad (1)$$

Where:

m_{water} is the initial mass of water, kg

C_{water} is the specific heat capacity of water, J/kgK

ΔT is the temperature increase in the water, ˚C

Q_{fuel} is the volume of fuel used, m^3

HV is the fuel heating value per unit volume, J/m^3

The Biomethane used in these tests was stored in a 100L tank at 200 bar as shown in Fig. 4. This is a tank similar to that used to store Natural Gas in a CNG converted vehicle. An estimate of the flame temperatures for both Biomethane and LPG were measured using a FLIR T200 infrared camera. Since the IR camera will only allow for a relative temperature difference to the estimated, it will not record the absolute temperature.

Fig. 4 Compressed Biomethane Tank

3. Results

A baseline case was established with LPG initially. Using the standard 0.7mm nozzle and a supply pressure of 1.2bar the flow rate of LPG was measured with the throttle valve fully opened. Then Biomethane replaced the LPG and the process repeated with larger nozzles. The resulting map is displayed in Fig. 5.

The triangular markers represent points where a stable flame was observed at all flow rates. These are considered safe and stable

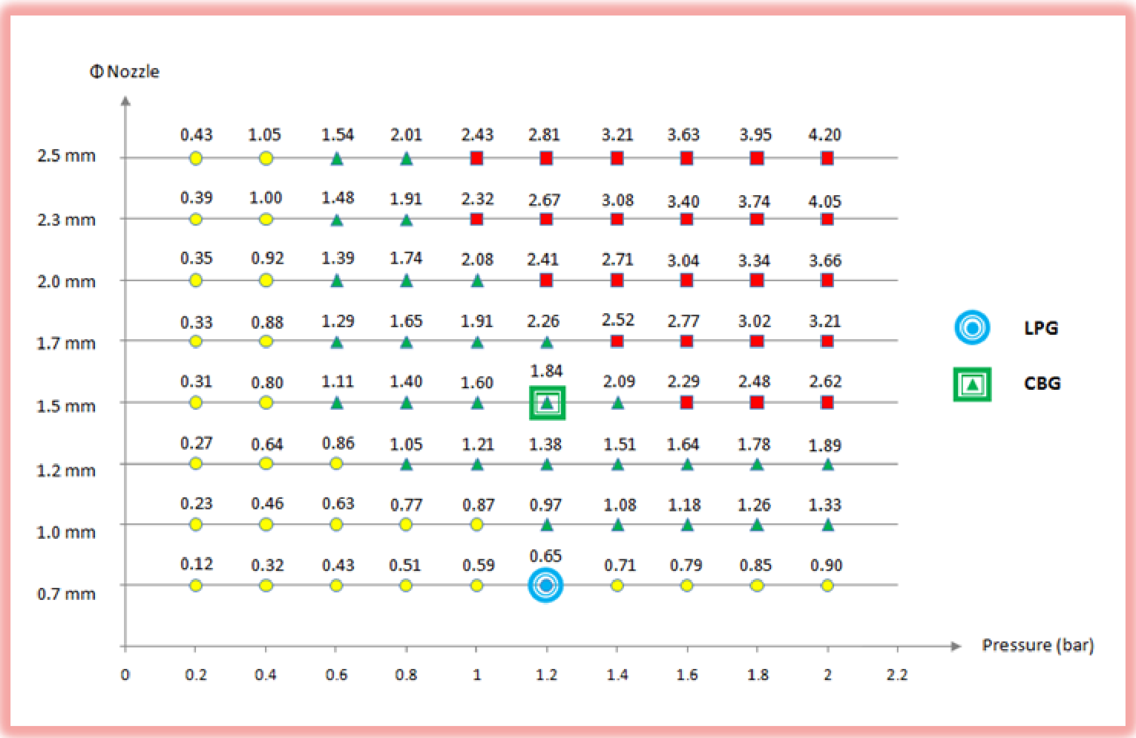

Fig. 5 Map for Commercial Stove using Biomethane

zones where the commercial stove can operate. So for example at a gauge pressure of 0.8 bar and a nozzle diameter of 1.5mm the stove can operate using Biomethane. The circular markers mean the flame was very small and potentially unstable. The square markers are points where the flame was unstable or where a flame was not observed on the heating head. It is not recommended to use the stove at either the circle or the square markers. The numbers above each symbol represent the measured flow rate at those conditions in m^3/hr. A point was selected as being the optimal. It was using a supply pressure of 1.2 bar and a nozzle size of 1.5mm. A similar or lower pressure is generally favored as then fuel leaks will not be an issue. There is a margin of safety in the selection as the nozzle size above and below it are also satisfactory. A comparison between both flames is shown in Fig. 6.

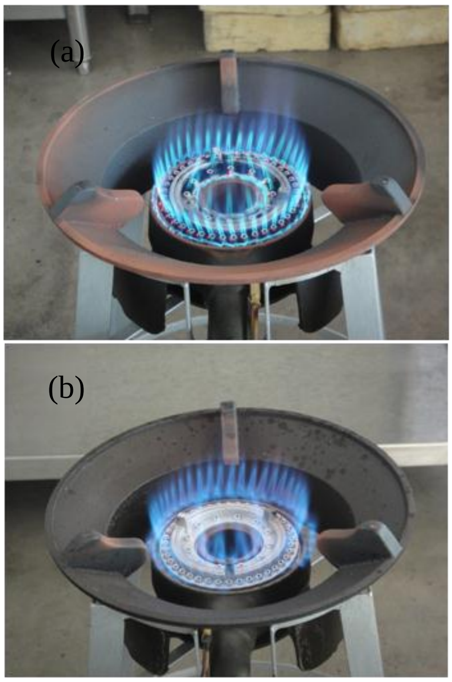

Fig. 6 (a) LPG Flame and (b) Biomethane Flame at the Optimal Conditions

Infrared pictures were taken for both the LPG and the Biomethane as shown in Fig. 7. Again, the absolute temperature will not be accurate but it will allow us to make a relative comparison. As can be seen a maximum temperature in both pictures was the same. This is only useful as a rough guide and should not be taken as the actual flame temperature.

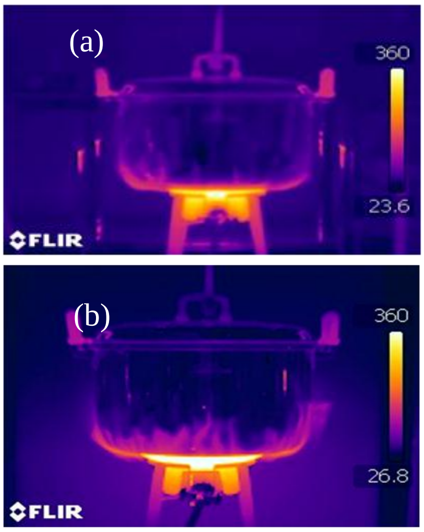

Fig. 7 Infrared Picture Comparison (a) LPG and (b) Biomethane

In order to check the stove efficiency of the Biomethane in comparison to LPG an efficiency test was performed. The standard used was DIN EN 203-2. This involved heating a 41.2kg container of water by 70˚C and measuring the time to do so. This represents how much energy is actually used in the cooking process with the rest being wasted as heat. The comparison between Biomethane and LPG is shown in table 1. The conditions used in the Biomethane testing were the optimal conditions with the stove valve fully opened to allow the maximum fuel flow.

Table. 1 Efficiency Testing Results

	Efficiency (%)	Heating Time (mins)	Heating Rate (kW)
LPG	54	30	12.8
Biomethane	41.5	28	16

4. Discussion

The purpose of this paper was to examine the possibility of using Biomethane in a commercial single cooking stove. The conclusion is that it is possible to use Biomethane so long as the pressure used and nozzle sizes used are matched appropriately. It is found that the existing nozzle size (0.7mm) cannot be used. No matter what pressure the Biomethane is set at the flame is small and unstable. Fig. 4 shows a map of the suitable nozzle sizes and pressures. The triangular markers represent the points with a stable flame. One particular point was selected as the optimal, the point at a pressure of 1.2 bar and a nozzle diameter of 1.5 mm. The standard pressure is 1.2 bar so therefore a pressure of 1.2 bar or lower should not cause any gas leakage problems. A 1.5 mm nozzle was chosen as the configuration is well within the working range and should be the most robust.

The adjustable valve, attached to the stove, which supplies the fuel to the burner, can be varied. It can be shut completely or open fully. The pressures in these tests are pressure measured before this valve. A trianglar point on Fig. 4 means that the flame is stable at any and all setting of this valve.

An IR camera was used to get the relative temperature difference between the LPG and the Biomethane flame. It showed that the LPG flame was almost the same temperature as the biomethane flame.

5. Conclusion

Using Biomethane in a commercial stove as a replacement for LPG is a possibility with only some slight stove modification. The results from efficiency tests showed that the Biomethane flame was about 12.5% less efficient than the LPG flame. This is because the optimal biomethane flame uses 16kW of energy for the same heating time as 12kW of LPG. This is not necessarily a problem for biomethane as its adaption will depend on its relative price. The effect of this on the price or suitability of using biomethane has yet to be investigated.

It should be noted that the biomethane used in all testing was 85% pure Methane and 15% CO_2 and minimal traces of other compounds. Given the robustness of the optimal point we can speculate that changing the fuel purity a little should not affect the results too much. Obviously if the purity changes a lot then a new data set should be collected. The practicalities of providing biomethane to vendors and the type of storage tank needed have not been addressed in this paper nor has an emission study been carried out yet. They will be the subjects of a separate study.

6. Acknowledgments

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