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# Energy for Sustainable Development



# Powering shuttle kilns with compressed biomethane gas for the Thai ceramic industry



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#### ARTICLE INFO

Article history: Received 19 May 2015 Accepted 5 August 2015 Available online 25 August 2015

Keywords: Biomethane LPG Shuttle kiln Rocket burner Shower burner Wobbe index

# ABSTRACT

The objective of this research is to substitute compressed biomethane gas (CBG) for liquefied petroleum gas (LPG) for use in industrial ceramic kilns. This is for both environmental and economic reasons. In Thailand, the ceramic industry employs directly and indirectly over 75,000 people mostly in Saraburi and Nakhon Lampang. It generates annual exports in excess of 30,000 million baht (approximately \$910 million US). In 2014, it used 577,000 tons of LPG a fossil fuel. Thailand has the potential to produce renewable biomethane, from agricultural waste, in quantities to meet this demand.

Small-scale ceramic kilns use two types of burners, a rocket type and a shower type. A mixing nozzle injects the fuel into the burner. This creates a natural draft which entrains the combustion air and both air and fuel exit at the burner head where ignition occurs. It is not possible to directly substitute CBG for LPG without making physical changes to these nozzles and adjusting the flow parameters. This research outlines a methodology for adapting the burners for CBG and experimentally verifying the predictions. Flame stability, temperature, emissions, and efficiency were measured and were equivalent to the LPG flames. Finally, the modified burners were tested inside a 0.1 m<sup>3</sup> shuttle ceramic kiln and used to fire greenware. It is estimated that a cost savings of up to 30% can be obtained using CBG, with a payback period of a little over three and a half years, factoring in the cost of the changeover.

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# Introduction

The purpose of this paper is to use a renewable fuel, biomethane, in place of a fossil fuel, LPG, for industrial kilns. Thailand has a rich history in the ceramic industry with certain manufacturing sites dating back 5000 years (Shaw, 1989). Ceramic firing can be thought of as a sintering type process to bond the clay molecules together at high temperatures ~1200 °C. There are two ceramic manufacturing clusters in Thailand at Saraburi and Lampang, and LPG is the most common heat source (Thai Ceramics).

Biomethane or CBG (compressed biogas) is a gas composed of mostly methane, carbon dioxide, and other gases such as hydrogen sulfide. It is produced in Thailand as a byproduct of agricultural waste. Information on this process can be found in Sakar et al. (2009) and Nasir et al. (2012). Once the waste has been biodegraded anaerobically, the biogas undergoes a cleaning process that gets rid of harmful gases and increases the purity of methane (Ryckebosch

\* Corresponding author. *E-mail address:* james@dome.eng.cmu.ac.th (J. Moran). et al., 2011). In this paper, once the biogas contains 85% methane or above, it shall be referred to as biomethane or CBG. The desire to change to biomethane stems from economic and environmental considerations. The final section will explain the economics, how government policies effect the LPG price in Thailand and what the cost would be to change to CBG.

The Wobbe Index (WI) for LPG is around 85 MJ/m<sup>3</sup> and for 85% biomethane, it is 36 MJ/m<sup>3</sup>. This means that these fuels are not directly interchangeable in a natural draft type of nozzle. For similar pressures, the energy flow through a nozzle from LPG will be greater than biomethane. This is expected since both fuels have different heating values and densities. Changes are needed to the nozzle in order to get the same energy from biomethane in a stable flame. A method for doing this has been outlined by Suwansri et al. (2014) for domestic cooking stoves. The research will adopt a similar method but applied to a shuttle kiln.

Once a stable biomethane flame, of comparable energy to the LPG flame, has been established at the burner head, other tests were performed in order to check the fuel's suitability. Efficiency testing was carried out, the flame temperature profile was measured, emissions of CO and  $NO_x$  were measured, and finally ceramic greenware (bowls) were fired in a kiln and compared for the different fuels.



Fig. 1. Total and industrial use of LPG in Thailand from (EPPO, 2015).

#### Industrial LPG use in Thailand

In 2014, Thailand used approximately 7.5 million tons of LPG (EPPO, 2015) of which 577,000 tons were for industrial use, as shown in Fig. 1. About 2 million tons were imported.

When the agricultural or industrial waste is initially broken down, the biogas contains approximately 50–70 % methane (CH<sub>4</sub>), 30–50% carbon dioxide (CO<sub>2</sub>), as well as small amounts of other gases such as hydrogen (H<sub>2</sub>) and hydrogen sulfide (H<sub>2</sub>S) (Gunaseelan, 1997). This is then usually purified in a scrubbing process to increase the methane percentage and extract the harmful hydrogen sulfide (Ryckebosch et al., 2011). A summary of the state of biogas production in Thailand is given by Aggarangsi et al. (2013). For this research, the final value of methane concentration was brought to 85% with carbon dioxide making up the remaining gas.

The substitution of biomethane for LPG has been demonstrated and explained for domestic stoves by Suwansri et al. (2014) and Suwansri et al. (2015). The methodology adopted in this study will follow that of Suwansri. The exit nozzle will be designed to keep the velocity of the CBG similar to the LPG velocity. This was previously found to entrain the correct amount of combustion air. Too much air resulted in an unstable flame or 'blow-off' while too little air resulted in incomplete combustion. Suwansri found that when the fuel exit nozzle velocities were kept constant, the problems of flame blowoff and incomplete combustion were minimized. The experimental setup and some preliminary results from this research were presented by Watit et al. (2015).

#### **Biomethane substitution For LPG**

To combust biomethane in a small shuttle kiln, the nozzle hardware must be physically modified. A higher volume flow rate of biomethane is needed. Simply increasing the pressure will not



Fig. 2. Energy flow through nozzle versus the Exit velocity for biomethane and LPG.

work since that will increase the nozzle exit velocity, entraining too much combustion air, resulting in blow-off at the tip. The diameter of the nozzle must be increased to accommodate the flow. The standard LPG nozzle diameter is 0.9 mm. A graph of the energy inflow versus the exit velocity for 5 different biomethane nozzle diameters along with the standard LPG nozzle is shown in Fig. 2. The maximum energy flow from an LPG nozzle is approximately 7 kW, so from this figure, it can be seen that the biomethane nozzle diameter should be somewhere between 1.4 and 1.7mm. This shall be the starting point for the experiments.

Also, from the analysis by Suwansri et al. (2014), an estimate for the increase in fuel supply pressure needed for biomethane is given by:

$$\frac{\Delta P_{biomethane}}{\Delta P_{LPG}} = \left(\frac{LHV_{LPG}}{LHV_{biomethane}}\right)^2 \frac{\rho_{LPG}}{\rho_{biomethane}} = 4.3 \tag{1}$$

Therefore, for equivalent heating rates, the supply pressure needed for biomethane is approximately 4 times that of the LPG. Since for a typical shuttle kiln the LPG is supplied at 1 psi we would expect the supply pressure for biomethane to be between 4 and 5 psi.

#### **Experimental setup**

## Equipment

The experimental setup up has been described before by Watit et al. (2015). The details shall be presented again briefly, since the referenced paper is written in the Thai language. The premise is to use biomethane in place of LPG for shuttle kilns. In order to do this, the process is divided into 5 segments.

- 1) Substitute biomethane for LPG in the kiln. Observe a stable flame of similar color to LPG.
- 2) Measure the efficiency of the biomethane burner.
- 3) Measure the flame temperature.
- 4) Measure the biomethane Emissions
- 5) Fire pottery or greenware in the kiln and compare with LPG fired pottery.

Fig. 3 shows the most commonly used natural draft burners, a rocket type and a shower type. The nozzle through which the fuel flows is identical in both.

All experiments were carried out with both burner types but the results from both types were all almost identical. So for brevity any result labeled "burner" refers to both types of burner and if there is a difference then it will be explicitly stated.

#### Results

#### Biomethane substitution

This section presents the results from modifying the injection nozzle in order to substitute biomethane for LPG into a shuttle kiln. The LPG nozzle diameter is 0.9 mm and the supply pressure is 1 psi. Fig. 2 estimates what the expected biomethane nozzle diameter should be. The physical nozzle diameter was varied from 1.0–2.0 mm in increments of 0.1 mm. The fuel supply pressure was varied and the resulting flames were monitored. The results are shown in Fig. 4. The circular markers meant the flame was high and yellow in color which meant that insufficient air was being entrained to properly combust the fuel. The diamond shaped markers meant the flame was lifting off the burner head, a result of too much entrained air relative to the fuel. The triangular markers were where a stable flame was observed that appeared to match the LPG flame.



Fig. 3. (a) Rocket type burner, (b) shower type burner.

As can be seen, the stable flames are at a pressure of 5 psi and nozzle diameters between 1.2 and 1.8 mm as predicted from Fig. 2 and Eq. (2). A mid-range value, a diameter of 1.4 mm, was chosen as the nozzle used in the remainder of the tests. The average biomethane energy output at this diameter was 3.1 kW, for

comparison the average output from the LPG nozzle was 2.9 kW. In all future tests, this flowrate shall be the one used. Fig. 5 shows the biomethane flame at these conditions and the LPG flame at its optimal setting (1 psi, 0.9 mm diameter nozzle, 2.9 kW).



Fig. 4. Biomethane substitution results.



Fig. 5. LPG flame, 1 psi, 0.9 mm, 2.9 kW (1), biomethane flame, 5 psi, 1.4 mm, 3.1 kW (2).



Fig. 6. Infrared flame temperature measurements. LPG (1) biomethane (2).

# Biomethane efficiency

Efficiency tests were run on the biomethane nozzles. These tests are based on the standard DIN EN 203-2. The efficiency test involved heating 7.8 kg of water by 70 °C and measuring the time and quantity of fuel to do so. The efficiency may then be obtained from:

$$\eta = \frac{m_{water} C_{water} \Delta T}{Q_{fuel} \times HV} \tag{2}$$

where  $m_{water}$  is the initial mass of water (kg),  $C_{water}$  is the specific heat capacity of water (J/kgK),  $\Delta T$  is the temperature increase in the water (°C),  $Q_{fuel}$  is the volume of fuel used (m<sup>3</sup>), and *HV* is the fuel lower heating value per unit volume (J/m<sup>3</sup>). The tests were repeated for



Fig. 7. Measured temperature versus distance from flame for both burners and both fuels.

5000  $\mathbf{0}_{2}$ 3586 4000 3368 CO (ppm@ 0% 3000 ■ LPG 2019 CBG 2000 1062 1000 (a) 0 Rocket Shower 50.0 NO<sub>x</sub> (ppm @ 0% O<sub>2</sub>) 40.0 24.7 30.0 22.9 ■ LPG CBG 4.7 20.0 6.5 10.0 (b) 0.0 Rocket Shower

Fig. 8. Emissions of CO and NO<sub>x</sub> from LPG and biomethane.

both fuels six times. The LPG gave efficiencies from 52.3 to 55.8%. The biomethane fuel gave efficiencies between 52.2 and 56.5% which are almost identical in practical terms.



Fig. 9. 0.1 m<sup>3</sup> Ceramic Kiln with Greenware.

## Biomethane flame temperature

A rough estimate of the relative flame temperatures can be obtained using a FLIR T200 infrared camera. Since it does not have the capability to measure the hottest temperature at the center of the flame, only the relative temperature at the surfaces of both flames. Selected thermal images are shown in Fig. 6 which show the surface of the biomethane to be about 30 °C hotter than the LPG.



Fig. 10. Temperature curve for Firing.

A more accurate temperature profile was obtained from a type Rthermocouple which was traversed laterally across the flame. The conditions again were 1 psi (2.9 kW) for LPG and 5 psi (3.1 kW) for biomethane. As can be seen from Fig. 7, the flame temperatures of both fuels in both burners are again almost identical from 5 cm from the flames. In the shower type burner, the biomethane does have a higher temperature, 660 °C versus 560 °C.

### Biomethane emissions

Fig. 8 shows the results of emission testing carried out with a combustion analyzer according to EN 203-1. The conditions for both tests were 1 psi LPG and 5 psi biomethane and the results presented are averaged over 3 tests.

Fig. 8(a) shows the pollutants CO, corrected to a state of 0% excess oxygen. The two columns represent the rocket and shower type burner, respectively. For LPG, the measured CO was 3586 ppm and 3368 ppm which the corresponding levels for biomethane were 1062 ppm and 2019 ppm. This is an average drop of 44%. Similarly the NO<sub>x</sub> levels of LPG were 24.7 and 22.9 ppm for both burners. For the biomethane, the levels were 6.5 and 14.7 ppm, which is also an average drop of 44%.

### Ceramic kiln results

The purpose of these ceramic kiln experiments is to fire ceramics with both different fuels and compare the resultant ceramic products. The ceramic kiln used was a  $0.1 \text{ m}^3$  volume kiln as shown in Fig. 9. A



Fig. 11. Comparison of final products fired with different fuels.



Fig. 12. Average price of LPG for industrial use in Thailand (from EPPO, 2015).

Capital costs for installing LPG.

Quantity	Price (Baht)
1	2863
1	375
	3238
	Quantity 1 1

#### Table 2

Capital costs for installing a CBG system.

Cost of biomethane or CBG				
Number	Equipment	Quantity	Price (Baht)	
1	CNG-Type 1 100L Tank	2	36,000	
2	Iron frame structure	2	7000	
3	High pressure regulator	1	2354	
4	Gauges, piping, valves nozzles and fittings	1	16,207 <b>61,561</b>	

kiln volume refers to the volume of product inside it and not the actual inner volume. It has 4 holes on the sides where the burner heads supply the heat. At the top of the kiln in the center is a thermocouple where the temperature inside the kiln is measured. The exhaust gases exit through a port in the middle of the floor and exit out of a stack. A damper is located in the stack. By closing the damper, the pressure and hence temperature inside the kiln increases. Another method to increase the temperature is of course to increase the fuel firing rate.

Unfired clay articles, or greenware, were supplied for firing by the Mee Sin Ceramic Company of Lampang. Twenty bowls were fired each time with a combined weight of between 11 and 12 kg as shown in



Fig. 14. Production costs of CBG as a function of production capacity from (*Energy Research* and *Development Institute*, 2013.)

Fig. 9. They were fired with both LPG and CBG and compared with a reference sample from Mee Sin. The firing process takes seven and a half hours during which the temperature must be ramped at a rate of 2 °C per minute up to a final temperature of 1200 °C. The temperature graph, which was provided by Tilda Kiln in Lampang is shown in Fig. 10. Superimposed on this theoretical graph are the actual temperature measurements from firing with both LPG and biomethane. They are difficult to distinguish because they track the required input accurately.

As can be seen from Fig. 10, the biomethane is capable of accurately tracking the required temperature rate. These tests were performed six times in total, three times with LPG and three times with biomethane. Once the ceramic bowls had cooled, they were removed from the kiln and inspected for cracks, chipping, damaged paintwork, water leaks, and any other sign of defects.

There was no visible difference in appearance between the factory default bowls and those fired in the shuttle kiln using LPG and biomethane. None of the approximately 60 bowls fired with biomethane suffered damage to its surface or color (Fig. 11).

## Economics of fuel substitution

The Thai government subsidizes the use of LPG, although for industrial use, LPG is subsidized less than for domestic cooking and transportation. The industrial price of LPG over the past 4 years is shown in Fig. 12. The price rose in 2012 due to a reduction in the subsidy and is falling in 2015 in response to falling petrochemical prices



Fig. 13. Two 100L Tanks of CBG (Type 1) at 20 MPa.

Table 3

Annual fuel savings.

-	
Description	Details
Ceramic kiln Firing times per year Kg of LPG used in one firing: kg/1 time Kg of CBG used in one firing, kg./1 time Price of LPG: Baht/kg Price of CBG. Baht/kg	$\begin{array}{c} 0.1 \ (m^3) \\ 144^a \\ 16.50 \\ 23.40 \\ 24.16^b \\ 12.28 \\ 111.20 \end{array}$
Fuel savings per firing: Baht/time	111.29
ruei saving per annum: Bant/year	16,025.47

<sup>a</sup> One day firing, 1-day cooling for a total of 288 days per year.

<sup>b</sup> Industrial price of LPG in March 2015.

internationally. A more complete picture of Thailand's energy policies can be found at Energypedia. According to the EFIA, an independent public organization under the energy ministry the LPG subsidy at the start of 2014 was costing the Thai government \$100 million per day (33.05 THB was equal to one USD on 01/05/2015).

The relatively high price from 2012 to 2014 led industrial customers to search for cheaper alternatives. Substituting with biomethane would also benefit the Thai government as it would reduce the subsidy. However the changeover from LPG to biomethane has an economic cost to the factory. The equipment cost incurred for using LPG is shown in Table 1 and the cost for installing a biomethane fuel delivery system is shown in Table 2. This biomethane delivery system has been described before in (Koonaphapdeelert et al., 2011). The biomethane is stored in 100L tanks at a pressure of 20MPa as shown in Fig. 13.

The biomethane system cost an extra \$58,323 (33.05 THB was equal to one USD on 01/05/2015) to install. The operators need to be able to recoup this cost from savings on the running costs. The cost of CBG depends on the production capacity of the raw biogas as shown in Fig. 14. If the production capacity were 333 Nm<sup>3</sup> of raw biogas per hour then the cost of the biomethane would be \$12.28/kg, (Energy Research and Development Institute, 2013). Presently, this assumed production rate is high but is seen as an achieveable goal in the future. Therefore, this economic analysis assumes a low bound for the price of biomethane and thus will give the shortest payback period.

Table 3 displays the costs of firing in a  $0.1 \text{ m}^3$  shuttle kiln. Each firing lasts approximately seven and a half hours and uses 16.5 kg of LPG or 23.4 kg of CBG. With an annual total of 144 firings per year (information obtained from the Mee Sin Ceramics at Lampang) yields annual fuel savings of B16,000.

The economics of changing to biomethane are displayed in Table 4. It assumes a 10-year life span and an interest rate of 8.1%. The capital cost of the CBG comes from.

Table 2 and the cost of CBG from Fig. 14. The internal rate of return works out at 24.4% and the payback period is 3 years and 8 months.

#### Discussion

The purpose of this research was to determine if biomethane could be substituted for LPG in shuttle kiln stoves. Environmental and economic reasons were the primary motivation for this switch. The biomethane used in this study contains 85% methane. Economically the payback period would be 3 years 8 months assuming the price of biomethane continues to fall as economies of scale are developed and the price of LPG remains the same or increases due to a lifting of government subsidies or a global increase in the hydrocarbon price. The next step was to modify the fuel injection nozzles to give a clean stable flame. The optimal settings were found to be a nozzle diameter of 1.4 mm and fuel supply pressure of 5 psi. The corresponding values for LPG were 0.9 mm and 1 psi.

#### Table 4

Economic analysis of changing over to CBG in a shuttle kiln.

Description	Details
Cost for changing LPG to CBG (Baht)	58,323.00
Life for CBG tank (years)	10
Interest rate assumed for analysis	8.10% <sup>a</sup>
Fuel saving (Baht/year)	16,025.47
NPV	\$\\$48,725.88
IRR	24.4%
Payback period (years)	3.6

<sup>a</sup> Average interest rate for commercial loans from two Thai banks in March 2015.

In the next step, the temperature profile was measured for both flames and efficiency tests performed based on the standard DIN EN 203–2. The temperature profile and efficiency results were very similar for both fuels. The emissions of CO and  $NO_x$  were found to be approximately 44% lower for the biomethane flame.

Finally a batch run was performed on ceramic products, in this case bowls to see the effectiveness of using biomethane. Testing was only performed with a 0.1 m<sup>3</sup> shuttle kiln. There was no discernable difference with the bowls fired using biomethane. The conclusion is that it is possible to change from LPG to biomethane for use in the ceramic industry. So long as the economics of the changeover are correct, then ceramics could be made with biomethane. This reduces consumption of fossil fuels and appears to have less harmful emissions also. Scale up and larger kilns should be tested first before deciding on the changeover.

## Acknowledgments

The authors would like to express their thanks to the Energy Policy and Planning Office at the Ministry of Energy and Center of Excellence for Renewable Energy at Chiang Mai University for supporting this research.

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