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Low-NO_X combustion of biogas from palm oil mill effluent using flameless combustion

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ABSTRACT – An experimental study of flameless combustion in a laboratory-scale furnace using natural gas, simulated biogas and palm-oil-mill-effluent (POME) derived biogas. Flameless combustion regime is achieved for natural gas, simulated biogas and POME biogas. POME biogas flameless combustion has slightly lower average furnace temperature (2.69% reduction) due to increased inert gas in the furnace chamber. Flameless combustion produce larger and more uniform combustion area (R_{tu} = 0.097) compared to conventional flame combustion (R_{tu} = 0.21). NO_X emission measurement has shown reduced NO_X emission in flameless combustion of natural gas, POME biogas and simulated biogas with average of 6 ppm.

1. INTRODUCTION

Flameless combustion is a new technology which has the advantage of high efficiency [1], and low NOx emission [2]. NOx is a dangerous chemical component which causes surface ozone formation and smog. Flameless combustion can also process low calorific value fuel which makes it an ideal candidate for combustion of renewable energy which usually has low calorific value [3, 4]. However, since biofuels', particularly biogas', calorific value is dependent on the raw source, there is a need to study the suitability of biogas derived from POME as fuel for a flameless combustor. In this study, focus is given to flameless combustion of POME derived biogas with a long term aim for industrial application.

2. METHODOLOGY

A readily available laboratory scale furnace is used in this experiment. The flameless combustor was run using three different types of fuels: natural gas, POME biogas and simulated biogas. Natural gas is used to represent commonly used gaseous fossil fuel. The POME biogas is sourced from a biogas capture system in Felda Maokil Palm Oil Mill, Labis, Johor. The simulated biogas is a mix of 75% natural gas and 25% carbon dioxide. During flameless combustion of simulated biogas, CO_2 is added to primary air pathway (green line in Figure 1). For each of the fuel type, the equivalence ratio is varied to see effect of lean, stoichiometric and rich flameless combustion. The equivalence ratio is controlled by changing the air flow rate and keeping the fuel flow rate constant.

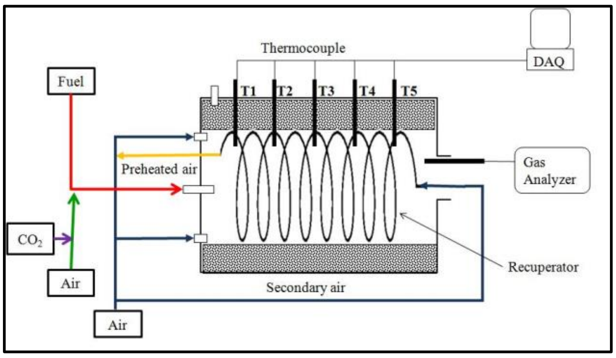

Figure 1 Flameless combustor experimental setup

A preheat time is allowed for about 1 hour before each experiment to heat up the furnace to about 800 ˚C. Temperature is measured at points T1 till T5 as in Figure 1. The data logger is connected to a desktop PC and records the furnace temperature in 1 minute interval. The NOx emission reading is taken using a gas analyzer at every 3-5 minutes time interval. The flameless combustion mode is allowed to run for at least 30 minute in each experiment.

3. RESULTS AND DISCUSSION

3.1 Visual Observation

Figure 2 shows the photographs of furnace chamber in conventional flame and flameless mode. In conventional flame, POME biogas fuel produced the least net radiation flux, which can be attributed to the lower calorific value of POME biogas compared to natural gas and simulated biogas. In flameless combustion mode, simulated biogas combustion produced slightly less net radiation flux compared to natural gas and POME biogas flameless combustion, due to lower CO_2 temperature in the fuel which slightly cooled the combustion region. In the future, it is recommended to let the CO_2 to reach room temperature before it is combusted for better comparison.

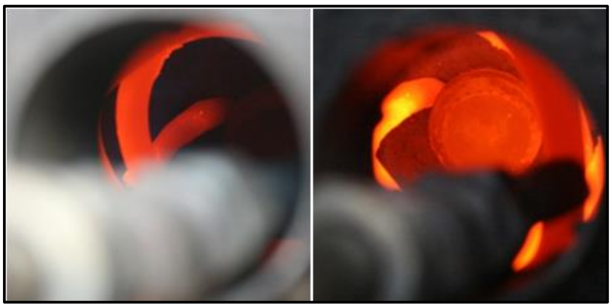

Figure 2 The conventional flame combustion of POME biogas (left) compared to flameless combustion of POME biogas

3.2 *Temperature Profile*

The average temperature in conventional mode is 796.2 ˚C in natural gas combustion and 782.4 ˚C in POME biogas combustion. For flameless combustion, the average temperature is 811.5 ˚C for natural gas and 789.7 ˚C for POME biogas. The average furnace chamber temperature is lower in POME biogas combustion compared to natural gas combustion in both flameless and conventional flame combustion. The temperature reduction is 2.69% in flameless combustion and 1.73% in conventional flame combustion.

To quantify the degree of temperature uniformity inside the combustion chamber, a temperature uniformity ratio (R_{tu}) is used [5]. In this experimental study, the R_{tu} for flameless combustion for both natural gas (R_{tu} = 0.041) and POME biogas (R_{tu} = 0.097) are less than the R_{tu} for conventional flame combustion using natural gas (R_{tu} = 0.21). The same trend is also seen in [18]. However, R_{tu} for POME biogas is higher than for natural gas, whereas in work by Colorado [6], the R_{tu} for biogas is lower than R_{tu} for natural gas.

3.3 *NO_X emission analysis*

Figure 3 shows the temperature variation and NOx emission during combustion of POME biogas in both conventional flame and flameless mode (separated by red line). The temperature change in flameless mode is slow compared to temperature change in conventional flame combustion. NOx emission is seen to drop drastically when the combustion mode is changed from conventional flame to flameless mode. The drop in NOx emission has been attributed to fewer hot spots in flameless combustion, which inhibits NO formation via thermal mechanism. NO formation via prompt mechanism is also expected to be insignificant. The NO formation in flameless combustion is from N2O intermediate pathway as has been shown in computational simulation of [5].

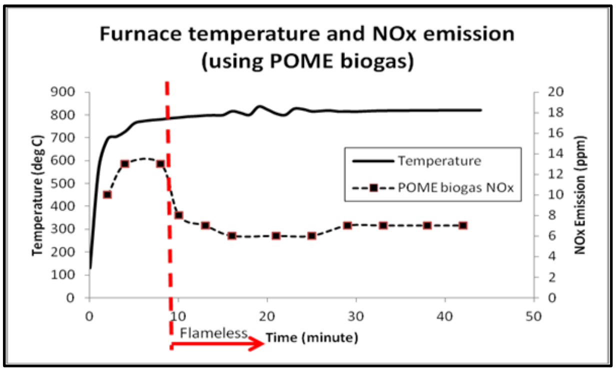

Figure 3 Furnace temperature and NO_X emission for conventional flame (left of red line) and flameless combustion of POME biogas (right of red line)

4. CONCLUSIONS

Flameless combustion method has been used in this study to provide low NOx combustion of POME biogas. It has been found in this study that a flameless combustor can easily function even if the type of fuel is changed.

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